MANAGEMENT STRATEGIES FOR THE CONTROL OF SOYBEAN RUST

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Introduction

The identification of Asian soybean rust in Paraguay in 2001(Morel and Yorinori, 2002) and its spread to over 90% of the soybean production in Brazil through the 2003 season has heightened the awareness that this disease will soon be a threat to production on the continental USA. With the yield losses this disease can cause it will have a big impact on the profitability of soybean production.

So how do we control the disease? To answer the question, we first need to understand a little about the biology of the organism and how it interacts with soybean. Asian soybean rust, caused by *Phakopsora pachyrhizi*, is an obligate parasite; it needs living tissue to survive. Urediniospores are the main spore stage. Teliospores and basidiospores have been produced but are not part of the disease cycle, since there is no known alternate host for basidiospores to infect. The pathogen penetrates directly, unlike the pathogens that cause rusts of wheat and corn. The infection process is not influenced by host surface features, stomata are not important in infection. Most parts of the soybean plant are infected, including the coleoptiles, leaves, petioles, stems and seedpods. Disease symptoms are primarily observed in the lower canopy until flowering. After flowering the symptoms are noticeable in the mid and upper canopy, where it causes rapid defoliation and yield loss. Yield loss can be due to pod abortion, and smaller and fewer seed. Protein is decreased but oil is not. One important feature is that the symptoms appear and spread rapidly after flowering. Spore production and lesion numbers increase after flowering, thus host age is important in the development of the epidemic.

The pathogen will not over winter in the Midwest. Like leaf or stem rust of wheat and the rusts of corn, soybean rust spores are wind blown and will most likely blow up from the south. *P. pachyrhizi* has a very broad host range and can infect over 90 species of plants in many genera, including Kudzu. Besides Kudzu, there may be other legume hosts found in areas where the fungus will over winter.

Cultural Practices

When you think of controlling a plant disease the methods that come to mind are cultural practices, host resistance, and pesticides. This presentation will try to cover what we know about cultural practices and fungicides for the control of Asian soybean rust. The recommendations to control soybean rust with cultural practices are mixed. Different green manures and fertilizer regimes did not affect rust severity or grain yield. Tillage is not a practice that will affect the disease; the pathogen will not survive long on debris. However, tillage may reduce the number of volunteer soybeans in the field, which may be important in the south where volunteers will provide inoculum for the next soybean crop. Removal of volunteer plants is a recommendation in India.

Planting dates. In Japan, a later planting date combined with fungicides and selection of less susceptible cultivars was recommended (Hartman *et al.*, 1992). Early planting was recommended in China, along with using a lime sulfur mix on resistant cultivars (Hartman *et al.*, 1992). In New South Wales, Australia, where rust outbreaks occur erratically, the recommendation was to use adapted later maturing cultivars, planted later (42). This recommendation was based more on yields being limited by moisture stress than on losses due to rust. In India, early season cultivars planted early were recommended.

Plant population. When two cultivars were grown at 35,000, 60,000 and 120,000 plants per ha the disease progression was highest in the dense planting, which also defoliated prematurely and had lower seed weights (Hartman *et al.*, 1992).

Row spacing. The jury is out on row spacing. Other rusts have been shown to move faster in wider rows. Narrow rows will also reduce the number of spores that escape the canopy when compared to wide rows, and spread within a field will be slower. However, narrow rows will provide a better environment for the disease to develop, increasing the number of successful infections. Row spacing will also have an effect on canopy penetration of fungicides. With both aerial and ground application, droplet size and number of droplets impacting the mid canopy were reduced in narrow rows when compared to wide rows (Hutchins and Pitre, 1984).

Overall, the cultural practice recommendations made in the past, including planting dates and the use of early or late maturing cultivars, were tied to the environments in the countries where those recommendations were made. Timing the planting and maturation of the crop to avoid environmental conditions that favor development of soybean rust and still maintain yield is the basis for each different recommendation. In the midwest most of the recommendations are not much help. Our planting window is narrower, and the development of the disease will be influenced by when the rust spores are blown into the area.

Fungicides

The primary tool in the control of the disease will be the use of fungicides. Single gene resistance has not been durable, partial resistance has been difficult to work with, leaving tolerance or yield stability as the selection method used in breeding programs. Tolerance is defined as yield stability in the presence of the disease compared to plots protected by fungicides (Hartman, 1995). Cultural practices have not been shown to be effective in control of the pathogen; recommendations were inconsistent and varied by location. The most effective practices were avoidance or were practices that maximized yields in the absence of the disease.

Fungicide Efficacy. Many fungicides have been evaluated to control soybean rust. Early research from Asia indicated that mancozeb was effective (Hartman et al., 1992). Other compounds available at the time were compared to mancozeb and were effective, but results varied by test (Table 1). More recently, fungicide trials in India (Patil and Anahosur, 1998) and Southern Africa (Levy et al., 2002) have identified several triazole compounds and triazole mixes. Among the more effective were flusilazole + carbendazim, difenoconazole, and triadimenol. The most recent trials in Africa and South America have identified additional triazoles, (eg. tebuconazole and tetraconazole), as well as several strobularins and strobularin mixes including azoxystrobin, pyraclostrobin, pyraclostrobin + boscalid and trifloxystrobin + propiconazole (Miles et al., 2003). Other compounds have been identified that reduce disease severity, but yield protection has been inconsistent. Further efficacy trials are continuing in both Africa and South America to identify additional products.

Labeled and Section 18 compounds. There are a total of three fungicides that are registered for use on soybean, labeled for soybean rust and are commercially viable (Table 2). These fungicides are Quadris®, Bravo®, and Echo®. Quadris is an azoxystrobin, Bravo and Echo are both chlorothalonils. There has been a section 18 exemption request for seven compounds or mixtures of compounds submitted to the EPA by the Departments of Agriculture of Minnesota and South Dakota (http://plantsci.sdstate.edu/draperm/SoybeanRustSection18). Not included on any of the lists are the sulfur, lime and elemental compounds, various oils, and other organic products that are not viable in a large commercial operation.

Timing and Number of Applications. The most recent recommendations for chemical control of soybean rust have come from Zimbabwe and South Africa (Levy et al., 2002). Early experiments evaluated the number of applications needed to protect the crop (Fig. 1). Treatments differed by date of first application and all treatments, except the non-protected control, received the last, or 108 days after planting (DAP), application. Applications were made at 20-day intervals starting at 28 DAP for the five application treatment. There were no differences in yields when fungicide application started 28 DAP (five applications) or 48 DAP (four applications). There was a slight yield loss when the first spray was applied at 68 DAP (three applications). Delaying fungicide application until 88 (two applications) and 108 DAP (one late application) resulted in significant yield losses. Flowering of both cultivars occurred between 50 and 60 DAP. When fungicides were applied during the vegetative growth stages (28 DAP), yields did not increase compared to applications that protected the crop from flowering through grain fill 48 and 68 DAP.

Experiments that evaluated the timing of applications in post flowering soybean were completed using two cultivars, Sonata and Soprano, treated with 50 g flusilazole + 100 g carbendazim (Punch Xtra) in single applications at either 50, 60, 70, 80 or 90 DAP, and two application treatments at 50+70 dap, 60+80 dap or 70+90 DAP. A three-application treatment (50+70+90 DAP) simulated the recommendation being made to farmers, and a four-application treatment was included to provide total rust control. Data indicate that most single applications did not protect yield (Fig. 2). However, if properly timed, a single application has been seen to protect yields when compared to treatments with two or more applications. The timing of the application was critical as applications 10 days earlier or later showed significant yield losses. This trend has been repeated in high and low disease situations. All treatments with two applications had yields similar to the three and four applications. Late applications had slightly less protection in Soprano, the indeterminate cultivar.

Recommendations. In Southern Africa, the recommendation was made to use a program with two or three fungicide applications (Levy *et al.*, 2002). Three applications were considered necessary in high disease situations, while two applications were recommended when disease severities were light. For best yield protection the first application was recommended at 50 DAP, at or just ahead of flowering. Subsequent applications 20 days apart were sufficient to control the disease. These recommendations were made in an attempt to limit the exposure of the crop to the disease due to difficulties in obtaining exact timing of a single application. This recommendation was supported by limited data from Paraguay where a single application at flowering had less yield protection than two applications, one at flowering with the second 20 days later (Miles unpublished data).

The number and timing of applications are critical for the control of soybean rust. The most efficient are applications applied during early reproductive growth, which allow protection through to crop maturity. The exact number of applications will depend on the length of the reproductive phase of the crop, duration of the compound and severity of the epidemic. Fungicide applications in early vegetative stages, although effective in reducing disease severity, have not been shown to be effective in protecting yield.

Application methods. Fungicides are not used in most soybean production areas; so little work has been done to develop an optimized, or commercially viable, fungicide application program. Both aerial and ground applications are used in South America. Multiple application methods are being used in Southern Africa, with the most effective methods being those where penetration and canopy coverage are the greatest. Examples of effective methods include air assist and high pressure lateral discharge equipment, increased pressure delivery and increased water volume per hectare. Currently, there is a multi-state project to evaluate high and low volume application in aerial and ground systems using predominantly 30-inch row spacing. Within the ground application program are different nozzle types that would be available on a commercial basis today. Included are the flat fan nozzle that would be used for Round up® application, as well as air induction and twin jet nozzles. Preliminary data from both aerial and ground application show the need for high volume (10 gal. aerial and 20 gal. ground applied) to penetrate the canopy into the middle third. There is need for additional experimentation before a fungicide application method can be developed to economically protect the soybean crop.

Future Outlook

With the movement of soybean rust into major production areas the use of fungicides in soybeans has increased. It would be expected that if soybean rust entered the continental U.S., there would be another dramatic increase of fungicides used on soybean, as the U.S. is the world's largest producer. The supply of fungicides in the U.S. is limited. If rust should occur next year, there is enough fungicide to treat 10 to 12 million acres of soybeans with a single application. Since soybean rust will not over winter in the midwest, but will arrive as wind blown spores, a forecasting system to monitor spore production and movement and predict high risk areas will play an important role in managing the disease. To develop a useful forecasting system, the basic epidemiology and spore transport biology of the pathogen need to be understood.

The future of soybean production on the continental U.S. will include fungicides once Asian soybean rust arrives. The development of a forecasting system, application methods that penetrate the canopy and cultivars with partial resistance or yield stability will be reduce the amount of fungicides that will be needed to protect the soybean production.

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Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

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Table 1. Summary of fungicides evaluated for control of soybean rust caused by Phakopsora pachyrhizi

Active ingredient	Products evaluated	Country where test were done	Summary of application trials and recommendations in the literature	References
Triadimefon	Bayleton®	India, Japan, Philippines, Taiwan, Thailand	Protection inconsistent when compared to Dithane M45, although it was used as a control in yield loss studies. EDBC's appear to be more effective but in limited testing up to 33% yield increases were seen. First application at flowering, 10 to 20 day intervals.	Hartman et al., 1992; Patil and Anahosur, 1998
Thiabendazole	Benlate®, Topsin M®	Thailand	Off registration in US, not as effective as Dithane M45, effective only when used with Plantvax, but no yield increase. Phytotoxic as a seed treatment.	Hartman et al., 1992
Chlorothalonil	Bravo®, Echo®	Brazil, India, Paraguay	Limited data available yield protection similar to or less than Mancozeb. Not as effective as other compounds in some studies.	Hartman et al., 1992; Miles et al., 2003; Patil and Anahosur, 1998
Ethylenebisdithio-carbamates (EDBC)*	Dithane-M45®, Mancozeb, Manzate D®, Zineb®, Maneb®	Australia, China, India, Philippines, Paraguay, Taiwan	The EDBC products have been effective in controlling soybean rust when applied 7 to 21 days apart, with the first applications as early as three weeks after planting and as late as flowering. Not all studies showed control of yield increases.	Hartman et al., 1992; Miles et al., 2003
Oxycarboxin	Plantvax®	India, Taiwan, Thailand	Not as effective as Dithane M45 or Manzate D, did not always control rust, yield protection varied by study. Apply when lesions first appear, then at 7 day intervals.	Hartman et al., 1992;
Hexaconazole	Contaf®	India	Effective in reducing disease and protecting yield, 25% yield increase in limited testing.	Patil and Anahosur, 1998
Propiconazole	Tilt®, Propimax®	Brazil, India, Paraguay	Effective in reducing disease and protecting yield, 33% yield increase in limited study. Two applications, 15 days apart, starting at flowering.	Miles et al., 2003; Patil and Anahosur, 1998

Difenoconazole	Score®	India, South Africa, Zimbabwe	Yield protection varied by study, more effective than Mancozeb. Two or three applications needed, starting at flowering.	Levy et al., 2002
Triadimenol	Shavit®	India, South Africa, Zimbabwe	Extremely effective in reducing disease incidence. Highest yielding treatment. Two or three applications needed, starting at flowering.	Patil and Anahosur, 1998
Flusilazole+ carbendazim	Punch Xtra®	South Africa, Zimbabwe	One of most effective fungicides in Africa. Two or three applications needed, starting at flowering	Levy et al., 2002
Tebuconazole	Folicur ®	Paraguay, Zimbabwe	Limited data, yield protection variable by location within studies.	Levy et al., 2002; Miles et al., 2003
Azoxystrobin	Quadris®	Brazil, Paraguay	Limited data, good control but single, late application did not control rust or protect yield.	Miles et al., 2003
Tetraconazole	Eminent®	Brazil, Paraguay	Limited data,	Miles et al., 2003
Pyraclostrobin	Headline®	Paraguay	Limited data, good rust control with yield benefits	Miles et al., 2003
Boscalid	Endura®	Paraguay	Limited data	Miles et al., 2003
Pyraclostrobin + boscalid	Pristine®	Paraguay	Limited data, good rust control with yield benefits	Miles et al., 2003
Trifloxystrobin + propiconazole	Stratego®	Paraguay	Limited data, good rust control with yield benefits	Miles et al., 2003
Fenbuconazole	Enable®	Paraguay	Limited data	Miles et al., 2003
Myclobutanil	Eagle®, Laredo®	Paraguay	Limited data	Miles et al., 2003

Table 2. Fungicides registered for used on soybean, labeled for Asian soybean rust or on the list of compounds for section 18 exemption.

			Registration status	
Compound	**Product**	**Company**	**Soybeans**	**Soybean rust**
Azoxystrobin	Quadris®	Syngenta	Yes	Labeled
Chlorothalonil	Bravo®	Syngenta	Yes	Labeled
	Echo®	Sipcam Agro	Yes	
Myclobutanil	Laredo®	DAS		Section 18
Propiconazole	Tilt®	Syngenta		Section 18
	Propimax®	DAS		Section 18
	Bumper®			Section 18
Pyraclostrobin	Headline ®	BASF		Section 18
Pyraclostrobin + boscalid	Pristine ®	BASF		Section 18
Tebuconazole	Folicur®	Bayer		Section 18
Trifloxystrobin + propiconazole	Stratego®	Bayer		Section 18
Tetraconazole	Eminent®	Sipcam Agro		Section 18

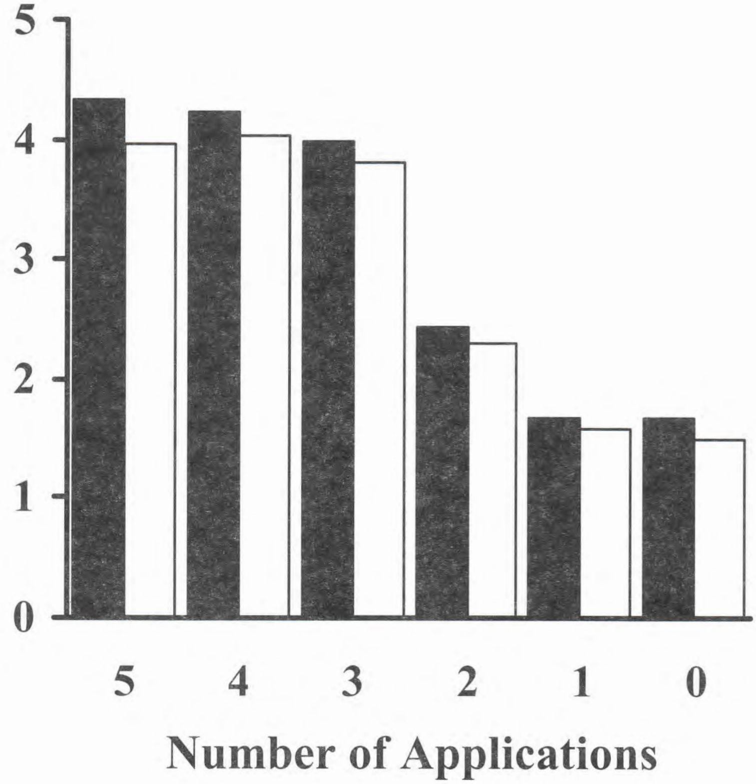

Figure 1. Kernel yield (t ha^{-1}, at 11% moisture content) of two soybean cvs ('Soprano': ■; 'Sonata': □) either sprayed with flusilazol + carbendazim, or left unsprayed at various dates after planting at the Rattray Arnold Research Station, Enterprise, Zimbabwe, in the 2000/2001 season.

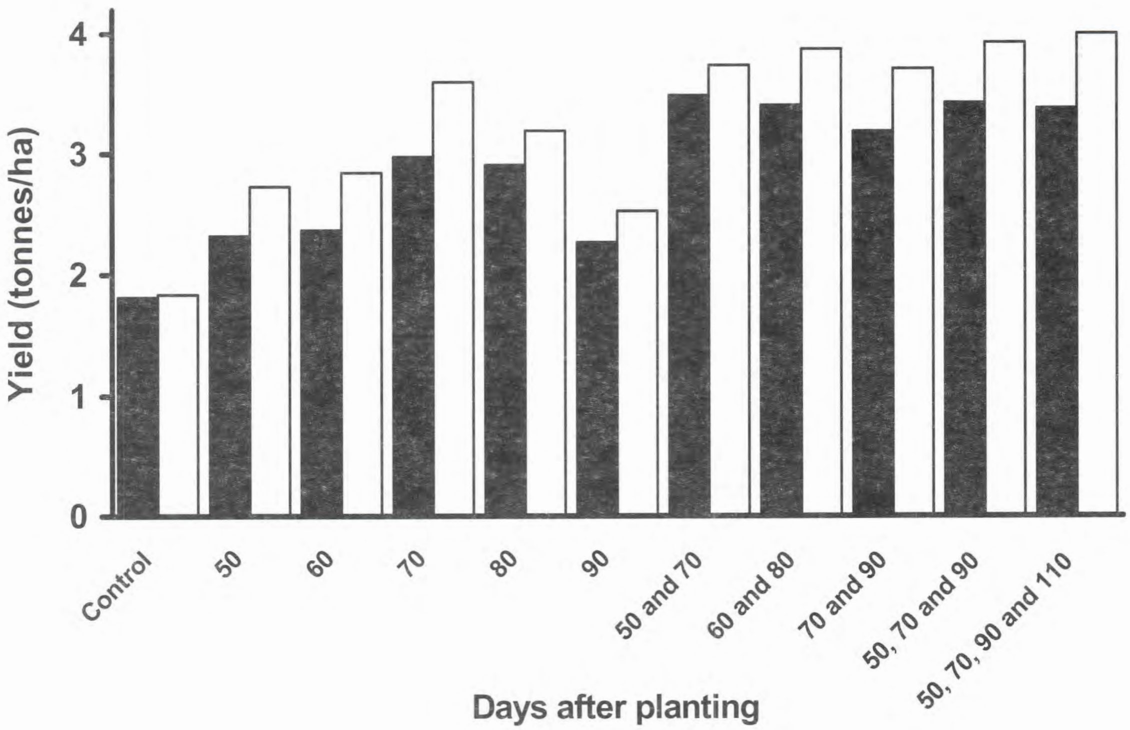

Figure 2. Kernel yield (t ha^{-1}, at 11% moisture content) of two soybean cvs ('Soprano': ■; 'Sonata': □) either sprayed with flusilazol + carbendazim, or left unsprayed at various dates after planting at the Rattray Arnold Research Station, Enterprise, Zimbabwe, in the 2000/2001 season.