Summary of the USDA Fungicide Efficacy Trials to Control Soybean Rust in Zimbabwe 2003-2004

Monte R. Miles[1], Clive Levy[2], and Glen L. Hartman[1, 3]

[1] USDA, Agricultural Research Service; [2] Commercial Farmers Union of Zimbabwe, Harare, Zimbabwe; [3] University of Illinois, Urbana, IL 61801.

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Executive Summary

The rapid spread of *Phakopsora pachyrhizi*, the causal agent of Asian soybean rust, in less than a decade into Southern Africa and South America and its potential for severe yield losses make soybean rust the most destructive foliar disease of soybean. Yield losses of 30% to 60% have been reported in areas of Southern Africa and South America, with losses of 100% reported from individual fields. This disease will have a major impact on soybean production in the continental U.S. Fungicides, although not commonly used on soybean in the U.S., will be the primary tool available to manage soybean rust. The objective of these trials was to evaluate soybean rust control and yield benefits from fungicides that are or could be registered for use in the continental U.S, including those listed in the Section 18 Emergency Exemption requests submitted to the EPA. Fungicide efficacy trials were located in the central soybean production area near Harare, Zimbabwe, during the 2003–2004 growing season. A total of 46 fungicide treatments were evaluated. The majority of the plots received either two or three fungicide applications, but there were single application treatments as well. All compounds controlled soybean rust when compared to the untreated control; disease severity was less in all the plots treated with fungicides. Yield increases were also seen with each of the fungicides in the Section 18 Emergency Exemption request.

The epidemic in Zimbabwe did not start until growth stage R5, as pods were being filled. The results of the efficacy trials reflect this, with significantly more severe soybean rust and greater yield losses in treatments with two applications than in those with three applications of the same product. The third application provided protection in the late season epidemic.

Introduction

The first confirmed report of *Phakopsora pachyrhizi* on the African continent came from Uganda in 1996 (Levy *et al*., 2002). Since then the pathogen has spread south, with reports from Kenya, Rwanda, Zimbabwe and Zambia through 1998 (Levy *et al*., 2002), and in eastern South Africa in 2001 (Pretorius *et al*., 2001). The pathogen has also been reported in western Africa, with reports from Nigeria in 1999 (Akinsanmi *et al*. 2001). The identification of Asian soybean rust in Paraguay in 2001 (Morel and Yorinori, 2002) and its spread to over 95% of the soybean production in Brazil through the 2004 growing season has heightened the awareness of this disease worldwide. The rapid spread of *P. pachyrhizi* and the potential for severe yield losses makes this the most destructive foliar disease of soybean. Yield losses of 20% to 60% reported in Asia with losses of 80% reported from experimental fields in Taiwan (Hartman *et al*., 1992). Yield losses of 40 to 60% were reported in Southern Africa with some reports of 100% loss in individual fields (Caldwell *et. al*, 2001). During the 2003-2004 growing season in Brazil, yield losses were estimated at 10% of the annual crop, an increase from the 5% yield loss estimate reported for the 2002-2003 growing season (Yorinori, pers. comm.). Soybean rust, if introduced into the U.S., could have a major impact on both total soybean production and production costs.

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

Table 1. Fungicides that are registered and labeled or on a Section 18 Emergency Exemption request for use on soybeans in the U.S.A. to manage Asian soybean rust.

			U. S. A. registration status	
Compound	**Product**	**Company**	**Soybeans**	**Soybean rust**
Azoxystrobin	Quadris®	Syngenta	Yes	Labeled
Chlorothalonil	Bravo® Echo®	Syngenta Sipcam Agro	Yes Yes	Labeled
Myclobutanil	Laredo®	DAS		Section 18[a] Approved 4/04
Propiconazole	Tilt® Propimax® Bumper®	Syngenta DAS Makhteshim-Agan		Section 18[a] Approved 4/04
Pyraclostrobin	Headline ®	BASF		Section 18[a]
Pyraclostrobin + boscalid	Pristine ®	BASF	(Yes[b])	Section 18[a]
Tebuconazole	Folicur®	Bayer		Section 18[a] Approved 8/04
Tetraconazole	Eminent®	Sipcam Agro		Section 18[a]
Trifloxystrobin + propiconazole	Stratego®	Bayer		Section 18[a]

a. http://plantsci.sdstate.edu/draperm/SoybeanRustSection18

b. Boscalid has been registered for use on soybean, but will not be labled for use against soybean rust.

results varied by test (Miles *et al*., 2003b). Fungicide trials in India (Patil and Anahosur, 1998) and Southern Africa (Levy *et al*., 2002) identified several triazole compounds and triazole mixes that controlled soybean rust. More recent trials in Africa and South America have identified additional triazoles, tebuconazole and tetraconazole, as well as several strobilurins and strobilurin mixes, including azoxystrobin, pyraclostrobin, pyraclostrobin + boscalid and trifloxystrobin + propiconazole (Miles *et al*., 2003c). Additional triazoles are commercially available in Brazil; among these are epoxiconazole, cyproconazole and metconazole. These fungicides have been shown to be very effective when mixed with one of the strobilurin compounds.

Labeled and Section 18 Compounds. There are three fungicides that are registered for use on soybean, labeled for soybean rust and are commercially available in the U. S. A. (Table 1). These fungicides are Quadris®, Bravo®, and Echo®. Quadris is an azoxystrobin; Bravo and Echo are both chlorothalonils. There has been a Section 18 Emergency 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). At least 24 other soybean-producing states have followed with requests of their own. Not included on any of the lists are the sulfur, lime, elemental compounds, various oils, and other organic products that may not be viable management tools in large commercial operations.

Timing and Number of Applications. The most recent experiments evaluating the timing and number of applications 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. There were no differences in yields when fungicide application started 28 days after planting (DAP) with five applications, or when application started 48 DAP with four applications. There was a slight yield loss when the first treatment was applied 68 DAP, with three applications in the season. Delaying fungicide application until 88 DAP, with two applications, and 108 DAP, with a single late application, resulted in significant yield losses. Flowering of the cultivars used in the study started 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. A single, properly timed application can protect yields when compared to treatments with two or more applications (Levy, 2004). The timing of the application was critical, as applications 10 days earlier or later showed significant yield losses. All treatments with two applications had yields similar to treatments with three or four applications. Late applications had slightly less protection in “Soprano”, the indeterminate cultivar when compared to the determinant cultivar “Sonata”.

Recommendations. In Southern Africa, the recommendation was made to use a program with two or three fungicide applications (Levy, 2004). 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 followed by another 20 days later (Miles, unpublished data).

In the near future, the primary tool to control soybean rust will be fungicides (Miles, *et al.*, 2003a). Fungicides have been used effectively in Southern Africa and South America to manage the disease. Cultural practices have not been shown to be effective in controlling the pathogen; recommendations were inconsistent and varied by location. The most effective cultural practices were those that maximized yields in the absence of the disease or were to plant during seasons were the disease could be avoided. Incorporation of resistance into commercial cultivars is several years away and will be made more difficult by the need to use non-race specific resistance. The number and timing of applications are critical for the control of soybean rust. Applications made during early reproductive growth that allowed protection through to crop maturity were the most efficient. The exact number of applications will depend on the length of the

Table 2. Products evaluated in the 2003-2004 Zimbabwae efficacy trials.

Company	Product Name	Applications	Active Ingredient	Ai/ha	Product /ha
DAS	Systhane 20EW (100g ai/ha)	2 vs. 3	myclobutanil	100g ai/ha	500ml/ha
DAS	Systhane 20EW (125g ai/ha)	2 vs. 3	myclobutanil	125g ai/ha	625ml/ha
DAS	Dithane DF	2 vs. 3	mancozeb	2400g ai/ha	3200g /ha
DAS	Propimax EC (125g ai/ha)	2 vs. 3	propiconazole	125g ai/ha	287ml/ha
DAS	Propimax EC (190g ai/ha)	2 vs. 3	propiconazole	190g ai/ha	437ml/ha
Syngenta	Tilt 3.6EC (4 oz/A)	2 vs. 3	propiconazole	126g ai/ha	292ml/ha
Syngenta	Quadris 2.08SC (6.2 oz/A)	2 vs. 3	azoxystrobin	110g ai/ha	440ml/ha
Syngenta	Quilt 200SE (14 oz/A)	2 vs. 3	azoxystrobin + propiconazole	a	1000ml/ha
Syngenta	Quilt 200SE (20 oz/A)	R1 only	azoxystrobin + propiconazole	a	1500ml/ha
Syngenta	Quilt 200SE (10.5 oz/A)	3	azoxystrobin + propiconazole	a	750ml/ha
Syngenta	Bravo 720 SC	2 vs. 3	chlorothalonil	1262g ai/ha	1750ml/ha
BASF	Headline (BAS 500F)	2 vs. 3	pyraclostrobin	168g ai/ha	672g/ha
BASF	Pristine (BAS 516F)	2 vs. 3	pyraclostrobin + boscalid	a	590g/ha
BASF	Endura + Penetrator	2 vs. 3	boscalid	224g ai/ha	320g/ha
Bayer	Folicure 3.6 F	2 vs. 3	tebuconazole	94g ai/ha	392ml/ha
Sipcam Agro	Eminent 125SL	2 vs. 3	tetraconazole	100g ai/ha	800ml/ha
Sipcam Agro	Echo 720	2 vs. 3	chlorothalonil	1440g ai/ha	2000ml/ha
ISAGRO	Domark 230 ME (85g ai/ha)	2 vs. 3	tetraconazole	85g ai/ha	370ml/ha
ISAGRO	Domark 230 ME (100g ai/ha)	2 vs. 3	tetraconazole	100g ai/ha	430ml/ha
ISAGRO	Domark 230 ME (115g ai/ha)	2 vs. 3	tetraconazole	115g ai/ha	500ml/ha
ISAGRO	Domark 230 ME (100g ai/ha)	R1 only	tetraconazole	100g ai/ha	430ml/ha
ISAGRO	Domark 230 ME (100g ai/ha)	R3 only	tetraconazole	100g ai/ha	430ml/ha
Crompton	Plantvax 75 WP	2 vs. 3	oxycarboxin	1 kg ai/ha	1330g/ha
Crompton	Procure 50 WS	2 vs. 3	triflumizole	350g ai/ha	700g/ha
Control	Punch Xtra	2 vs. 3	flusilazole + carbendazim	a	400ml/ha
Control	No fungicide				

a. Product is a mixture of two active ingredients so individual rates are not presented.

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.

Methods

Fungicide efficacy trials were located in the central soybean production area near Harare, Zimbabwe. A total of 24 fungicide treatments were evaluated in plots that received either two or three fungicide applications (Table 2). The first application was at growth stage R1 (first flower) with subsequent applications spaced 20 days apart. There were three treatments with a single application; Quilt® (20 oz/A) and Domark® (100g ai/ha) both applied at growth stage R1 and Domark® (100g ai/ha) applied at growth stage R3. Field design was a split plot with 4 replications per location. The main effects were fungicide treatment, product and rates, with early and late applications as the subplot. The early application was either a single application at R1 or the standard two-application protocol. The late application was either a single application at R3 or the standard three-application protocol. Fungicides were applied using a rate of 400 L water/ha with a hand-operated backpack sprayer fitted with a pressure regulator and a Lurmark® F110/1.6/3 flood-jet nozzle. Two locations were used in the study. Rattray Arnold Research Station (Rattray Arnold) was planted mid-December using a determinant cultivar "Storm". An indeterminate cultivar "Safari" was used at the Gwebi Variety Testing Center (Gwebi) and was also planted mid-December. Plots were six rows wide with row spacing of 75 cm at Rattray Arnold and 90 cm at Gwebi. Harvested plot sizes were 9 m^2 at the Gwebi and 7.5 m^2 at the Rattray Arnold. Seed was weighed and all results were adjusted to 13% moisture. Each plot was bordered by a pair of soybean rows that were left untreated to act as both a buffer between plots and as a source of inoculum for the plots. An early-planted, early-maturing border was planted around the test field at both locations to provide additional inoculum.

Disease severity was assessed using the International Soybean Rust Assessment Rating System (Shanmugasundaram, 1977); the data was converted into a percent disease severity to allow for statistical evaluation (Table 3).

Table 3. Transformation of the International Soybean Rust Scoring System into percent soybean rust severity

International Soybean Rust Scoring System		Transformed soybean rust severity (%)
Position[a]	Severity[b]	
1	1	0
1	2	12
1	3	16
1	4	20
2	1	24
2	2	37
2	3	50
2	4	58
3	1	63
3	2	76
3	3	88
3	4	94

a. Position is the uppermost area of the canopy where soybean rust is found, 1=lower 1/3 of the canopy, 2= mid-canopy and 3 = upper 1/3 of the canopy.

b. Severity is evaluated as 1= no disease, 2= some disease, 3= moderate disease and 4 = severe disease.

Results and Discussion

Soybean rust was present as late epidemics that were severe at both locations of the study. At Rattray Arnold, the first detection of the pathogen was 79 days after planting when the soybeans were in early growth stage R5, and 107 days after planting at Gwebi when the soybeans were in early growth stage R6. Disease severity reached 94% in the control plots, with mean final soybean rust severity of 40% and 45% across all treatments at Gwebi and Rattray Arnold, respectively (Table 4). This late epidemic will have an effect on how the results of the trials are interpreted, as all treatments were applied protectively. The 20-day application schedule and the difference between 2 vs. 3 applications should allow for examination of the relative residual effects and/or the curative properties of the different fungicides. Plots matured 126-130 DAP in Gwebi and 115-118 DAP at Rattray Arnold.

The split plot analysis identified significant differences between locations, among fungicides, as well as between the 2 vs. 3 applications within fungicides for final soybean rust severity, yield and 1000 seed weight. However, there was also a significant location x fungicide interaction confounding the results for all three traits. A significant interaction of the application within fungicide x location was seen only with the final disease severity.

Final Soybean Rust Severity. Final soybean rust severity ranged from 0% to 95% for the fungicides treatments evaluated in the study. Significant differences were seen between locations, fungicides and application within fungicides there was also a significant application within fungicide x location interaction (Table 5). Mean final soybean rust severity was greater at Rattray Arnold than at Gwebi, with mean severities of 45% and 40% respectively. The mean final soybean rust severity was 66% and 57% in the 2-application treatments vs. 15% and 31% in the 3-application treatments at Gwebi and Rattray Arnold, respectively. Thus, there was more soybean rust in the 2-application treatments at Gwebi, but the final soybean rust severity was greater at Rattray Arnold in the 3-application treatments. This result is not surprising; the epidemic started at least three weeks sooner at Rattray Arnold, which was planted with a determinant variety that did not add new leaves after flowering. The epidemic started later at Gwebi, which had a longer growing season and was planted with an indeterminate cultivar. The indeterminate cultivar developed new leaves after flowering that would need to be protected. The additional 10 to 12 days to maturity combined with new unprotected leaf material resulted in an increased final soybean severity for the 2-application treatments at Gwebi. These differences contributed to the significant interactions identified within the experiment.

The application within fungicide x location interaction can be readily identified with the final soybean rust severities for both Plantvax® and Procure®. Both products had 0% final soybean rust severity with 3 applications at Gwebi, which was lower than expected from the final soybean rust severities at Rattray Arnold or with 2 applications at Gwebi. A similar pattern was seen with Propimax® (190g ai/ha). The no-fungicide control also contributed to the interaction; final soybean rust severity did not vary between 2 vs. 3 applications or between the two locations, but was a mean of 94%.

When fungicides are compared using 2 vs. 3 applications from both locations, the triazole products Domark®, Eminent® and Folicur® were found to have a final soybean rust severity of 0% at all locations. This group was followed by a grouping that consisted of Systhane® (125 g ai/ha), Domark® (85 g ai/ha), the commercial control Punch Xtra®, and Echo®, which all had significantly lower final soybean rust severities than the no-fungicide controls. The next group of fungicides differed from the control only in the 3-application treatment and consisted of Systhane® (100g ai/ha), Headline®, Pristine®, Propimax®, Quilt®, Quadris®, Tilt®, Procure® and Plantvax®. Although Echo®, a chlorothalonil fungicide, was among the better performing products, Bravo®, a similar chlorothalonil, performed the same as Dithane® and was better than the no-fungicide control only in the 3- application treatment at Gwebi. The difference between these two similar products cannot be explained except that Echo® was applied at a rate of 1440 g ai/ha vs. 1265 g ai/ha for Bravo®; both were SC formulations.

The effect of rate and timing of application on final soybean rust severity was seen within the experiment. Domark®, at 100 or 125 g ai/ha, had final disease severity of 0% with both 2 and 3 applications. When applied at 100g ai/ha at either R1 or R3, the final soybean rust severities remained 0%. When applied at a lower application rate of 85 g ai/ha, the final soybean rust severity was 69% for the 2-application treatment at Gwebi. When the different rates and timings of Quilt® were compared, the 3-application treatments at 10.5 oz/A and 14 oz/A had low soybean rust severity, under 30%. The 2-application treatments at 14 oz/A and the single 20 oz/A application at growth stage R1 did not reduce soybean rust and were above 90% severity. Three applications of Dithane®, Echo®, and Bravo® were effective in reducing disease severity but the 2-application treatments did not.

Mean yields. Mean yields were 3565 and 3791 Kg/ha for all the treatments at Gwebi and Rattray Arnold (Table 5). There were significant differences between the two locations as well as between the 2 vs. 3-application treatments; yields were lower at Gwebi than at Rattray Arnold (Table 5) and in the 2-application treatments vs. the 3-application treatments (Table 6). There was a significant fungicide x location interaction as well as a significant application within fungicide effect. The application within fungicide x location interaction was not significant.

In both Gwebi and Rattray Arnold, the mean yields of all of the fungicide treatments were greater than the untreated control (Table 5). The fungicides with the highest mean yields at both locations included: Headline®, Domark®, Folicur, Quilt® (10.2 oz/Ac) and Propimax®. Dithane® and the single R3 application of Domark® (100 g ai/ha) had low mean yields at both locations. The fungicide x treatment interaction can be seen with several of the fungicides, where mean yields were lower than expected at Gwebi compared to the mean yields at Rattray Arnold. The epidemic at Gwebi started when the crop was in early R6, almost three weeks later than at Rattray Arnold. The late start of the epidemic combined with the later harvest of the indeterminate cultivar “Safari” produced a situation where several fungicides were unable to maintain yield protection.

The 2-application treatments tended to have lower mean yields than the 3-application treatments of the same fungicide (Table 6). Among the 2-application treatments, Domark®, Folicur®, Eminent®, and Propimax® had the highest mean yields; all of these products are triazoles. The strobilurin fungicide, Headline®, had mean yields similar to these products. When the mean yields from the 3-application treatments were compared, there were no significant differences among the triazole or the strobilurin fungicides. Fungicides with the highest mean yields included Headline®, Domark®, Folicur®, Eminent® and Propimax®, although most of the fungicides had mean yields that did not differ significantly from Folicur®, Eminent® or Propimax®. The significant application within fungicide effect was seen with Pristine®, Endura®, and Bravo®. All three products had mean yields in the 2-application treatments that were lower than expected compared to the mean yields in the 3-application treatments. Other fungicides that may have contributed to this effect are Headline®, which had very high mean yield with three applications, and both rates of Systhane®, where the mean yields of the 2-application treatment were similar to those of the 3-application treatment.

The single 20 oz/A application of Quilt provided some yield protection when compared to the control (Table 6), however, when compared to three applications at 10.5 oz/A, the protection was lower. The difference between the 10.5 oz/A rate of Quilt® and the 14 oz/A rate can only be attributed to a low mean yield for the 14 oz/A rate at Gwebi. There were three plots at this location where the 3–application treatments had mean yields less than 2800 Kg/ha, lower than the 2-application plots within the pair and similar to the control plots for those replications. This was not seen at the Rattray Arnold location.

The single applications of Domark® did not differ statistically when applied at growth stage R1 or R3, although the R3 application had a higher mean yield. The three rates of Domark® were also not statistically different although the lower rate (85 g ai/ha) tended to have higher yields than the two higher rates (100 and 115 g ai/ha).

1000 seed weights. Mean 1000 seed weights were 209 g at Gwebi and 200 g at Rattray Arnold; these differences were significant (Table 7). Since the epidemic started earlier at Rattray Arnold, this is not unexpected. There were also significant differences among fungicides and between the 2 vs. 3 applications within fungicides (Table 8) as well as a significant fungicide x location interaction (Table 7). The application within fungicide x location interaction was not significant. All fungicides had greater seed weights than the control. However, at Rattray Arnold, Quilt® (20 oz/A at R1) and Endura® did not differ from the control. High seed weights were seen with both the triazole and strobilurin products at each location. Folicur®, Headline®, Quilt® (10.5 oz/A), Systhane® (100 g ai/ha), Domark® (at both 85 and 100 g ai/ha) and Echo® had the highest seed weights in Gwebi. Quilt® (10.5 oz/A), Echo®, Eminent®, Domark® (at 100 and 115 g ai/ha) and Headline® had the highest seed weights at Rattray Arnold. The fungicide x location interaction was seen with the fungicides Folicur®, Systhane® and Endura®; all had high seed weights at Gwebi compared to the weights at Rattray Arnold.

Seed weights were significantly different between the 2 and 3-application treatments, with the 3-application treatment having a higher mean weight (Table 8). All fungicides, whether applied as 2 or 3-applications, had higher seed weights than the no-fungicide control. The highest mean seed weights for both the 2 and 3-application treatments were seen with the fungicides Headline®, Folicur®, Echo®, and Domark® (100 g ai/ha). The lowest seed weights were seen with Bravo®, Dithane®, Plantvax® and Endura® at both locations. There was a significant application within fungicide effect that can be seen in Pristine®, Eminent®, Propimax®, Quadris®, Tilt®, Quilt®, and Procure® where the seed weights of the 2-application treatments were significantly lower than the weights of the 3-application treatments.

The single R1 application of Quilt® at 20 oz/A provided some protection compared to the control. Quilt® (10.5 oz/A) applied three times was among the products with the highest seed weights. This is in contrast with the 14.5 oz/A application of Quilt®, where the 2 and 3-application treatments were similar for seed weight. The single R1 application of Domark® (100 g ai/ha) did not provide the protection of the single R3 application at the same rate or the 2 and 3-applications of the 85, 100 and 115 g ai/ha rates.

Conclusions

All the fungicides evaluated in the trial reduced the effects of soybean rust on disease severity, yield and 1000 seed weight. However, there were differences among the fungicides in final disease severity, yield and 1000 seed weights across locations and within a single location of the trial. This is not unexpected; the products tested include triazole, strobilurin, chlorothalonil and other classes of fungicides, each of which differs in mode of action, absorption, translocation and residual activity. The interaction of the products with the location is also not unexpected. The two locations differed in growth habit of the cultivar and the growth stage of the crop when soybean rust was first detected. The interactions of fungicide with application number and location were the result of the differences in the activity of the products under the 20-day application schedule.

Among the treatments, Dithane® and Bravo® reduced the soybean rust severities the least. These fungicides are not absorbed into the leaf, but are protectant fungicides that provide control by limiting infection and spore germination on the leaf surface; once an infection occurs these products do not interfere with fungal development. The experimental protocol used in this trial was to apply fungicides at 20-day intervals; this interval is too long for these products. Labeled recommendations for these fungicides are to apply at 7 to 14-day intervals, depending on rainfall.

The triazole and strobilurin fungicides, as well as mixes of the two, were effective in reducing soybean rust severity and protecting yield. However, individual fungicides differ in their strengths. The triazole fungicides are sterol inhibitors, interfering with sterol biosynthesis in fungal membranes. As a group, the triazoles have short residual periods and move rapidly through the leaf. Under application schedules longer than 14 days they may be dissipated from the plant tissue unless high rates are used. The strobilurin products have a longer residual, moving slower through the leaf tissue, but are not as effective in controlling infections that are established. If infection levels are too high when the strobilurin fungicides are first applied, they may not protect yields. Strobilurin fungicides limit spore germination and fungal growth, but do not always kill established rust infections. With the single site mode of action from each group of fungicides, it is necessary to limit use to one application per season per class. The relative curative ability of the triazoles and the interaction between application rates and residual effects need to be evaluated. Additional research on the timing of application and rotation of triazoles and strobilurin fungicides is also needed, as are additional locations of the 2 vs. 3 application comparisons used in this study.

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Table 4. Mean final soybean rust severity of the fungicides evaluated in 2 vs. 3 applications at two locations in the 2003-04 Zimbabwe efficacy trials.				
	Final soybean rust severity (%)			
	Gwebi Variety Testing Center[b]		Rattray Arnold Research Station[b]	
Fungicides with 2 vs. 3 applications	Mean of 2 applications	Mean of 3 applications	Mean of 2 applications	Mean of 3 applications
Domark 230 ME (100g ai/ha)	0 O	0 O	0 O	0 O
Domark 230 ME (115g ai/ha)	0 O	0 O	0 O	0 O
Eminent 125SL,	0 O	0 O	0 O	0 O
Folicur 3.6 F	0 O	0 O	0 O	0 O
Systhane 20EW (125g ai/ha)	60 G H	0 O	0 O	0 O
Domark 230 ME (85g ai/ha)	69 D E F G	0 O	0 O	0 O
Punch Xtra	60 G H	0 O	47 H I J	0 O
Echo 720,	69 D E F G	0 O	63 F G	0 O
Systhane 20EW (100g ai/ha)	82 A B C D	0 O	60 G H	0 O
Headline (BAS 500F)	88 A B C	0 O	60 G H	0 O
Pristine (BAS 516F)	85 A B C	0 O	61 F G H	9 N O
Procure 50 WS	78 B C D E	0 O	91 A B	44 I J
Propimax EC (125g ai/ha)	93 A B	0 O	88 A B C	34 J K L
Plantvax 75 WP	87 A B C	0 O	91 A B	56 G H I
Quilt 200SE (14 oz/A)	90 A B C	28 K L M	82 A B C D	37 J K L
Propimax EC (190g ai/ha)	91 A B	16 M N	93 A B	47 H I J
Tilt 3.6EC (4 oz/A)	93 A B	37 J K L	76 C D E F	44 I J
Quadris 2.08SC (6.2 oz/A)	87 A B C	37 J K L	90 A B C	66 E F G
Bravo 720 SC	88 A B C	34 J K L	93 A B	88 A B C
Endura + Penetrator	88 A B C	44 I J	94 A	94 A
Dithane DF	94 A	47 H I J	94 A	85 A B C
No fungicide control	94 A	94 A	94 A	94 A
Single application treatments				
Domark 230 ME (100g ai/ha) R1[a]	0 O	O	0 O	
Domark 230 ME (100g ai/ha) R3[a]		0 O		0 O
Quilt 200SE (20 oz/A) R1[a]	94 A		95 A	
Quilt 200SE 10.5 oz/A - 3 applications		25 L M		40 J K
Application mean[b]	66 W	15 Z	57 X	31 Y
Location mean[b]	40 A		45 B	

a. Fungicides applied once at growth stage R1 or R3.

b. Means of the fungicides at both locations were separated using Students LSD (p=0.05); different letters indicate significant differences. The location interaction occurs where treatments have different letters at the two locations.

Table 5. Mean yield of the fungicides evaluated at the two locations in the 2003-04 Zimbabwe efficacy trials when 2 and 3- applications treatments were combined.

Fungicide treatments	Mean yield (Kg/ha) at 13% moisture			
	Gwebi Variety Testing Center[b]		Rattray Arnold Research Station[b]	
Eminent 125SL,	3566	F G H I J K L M N	4295	A
Headline (BAS 500F)	4147	A B	4093	A B C
Punch Xtra	3326	K L M N O	4081	A B C
Systhane 20EW (125g ai/ha)	3401	I J K L M N O	4072	A B C D
Domark 230 ME (115 g /ha)	3382	J K L M N O	4070	A B C D
Domark 230 ME (100g ai/ha) R3[a]	3379	J K L M N O	4069	A B C D
Propimax EC (125g ai/ha)	3722	B C D E F G H I J K L	4035	A B C D E
Domark 230 ME (100g ai/ha)	3565	G H I J K L M N	4035	A B C D E
Domark 230 ME (85g ai/ha)	3936	A B C D E F G	4010	A B C D E F
Folicur 3.6 F	3887	A B C D E F G H	3969	A B C D E F G
Systhane 20EW (100g ai/ha)	3694	C D E F G H I J K L M	3888	A B C D E F G H
Quadris 2.08SC (6.2 oz/A)	3666	C D E F G H I J K L M	3883	A B C D E F G H
Domark 230 ME (100g ai/ha) R1[a]	3446	H I J K L M N O	3883	A B C D E F G H
Quilt 200SE (14 oz/A)	3172	N O	3868	A B C D E F G H
Quilt 200SE 10.5 oz/A - 3 applications	4343	A	3860	A B C D E F G H
Pristine (BAS 516F)	3549	G H I J K L M N O	3846	B C D E F G H I
Echo 720,	3606	E F G H I J K L M N	3813	B C D E F G H I J
Tilt 3.6EC (4 oz/A)	3683	C D E F G H I J K L M	3812	B C D E F G H I J
Procure 50 WS	3293	L M N O	3789	B C D E F G H I J
Bravo 720 SC	3119	O P	3784	B C D E F G H I J
Plantvax 75 WP	3277	L M N O	3750	C D E F G H I J K
Propimax EC (190g ai/ha)	3788	B C D E F G H I J	3574	F G H I J K L M N
Dithane DF	3631	D E F G H I J K L M	3398	J K L M N O
Endura + Penetrator	3753	B C D E F G H I J K	3262	M N O
Quilt 200SE (20 oz/A) R1[a]	3708	C D E F G H I J K L	2758	M N O
No fungicide control	2660	Q	2675	P Q
Location mean[b]	3565	X	3791	Y

a. Fungicides applied once at growth stage R1 or R3, mean of 4 not 8 plots per location when 2 and 3 application treatments were combined for comparison between locations.

b. Means of the fungicides at both locations were separated using Students LSD (p=0.05); different letters indicate significant differences. The location interaction occurs where treatments have different letters at the two locations.

Table 6. Mean yield for each fungicide treatment when means are combined from the two locations of the 2003-04 Zimbabwe efficacy trials.

	Mean yield (Kg/ha) at 13% moisture			
Fungicides with 2 vs. 3 applications	**Mean of 2 applications[b]**		**Mean of 3 applications[b]**	
Headline (BAS 500F)	**3834**	B C D E F G H	**4406**	A
Domark 230 ME (85g ai/ha)	**3792**	B C D E F G H I	**4154**	A B
Folicur 3.6 F	**3805**	B C D E F G H I	**4051**	A B C D
Eminent 125SL,	**3836**	B C D E F G H	**4025**	A B C D
Propimax EC (125g ai/ha)	**3751**	B C D E F G H I J	**4006**	A B C D E
Pristine (BAS 516F)	**3440**	H I J K	**3955**	B C D E F
Domark 230 ME (100g ai/ha)	**3660**	C D E F G H I J K	**3940**	B C D E F G
Quadris 2.08SC (6.2 oz/A)	**3616**	D E F G H I J K	**3932**	B C D E F G
Tilt 3.6EC (4 oz/A)	**3573**	E F G H I J K	**3921**	B C D E F G
Domark 230 ME (115g ai/ha)	**3548**	F G H I J K	**3904**	B C D E F G
Echo 720,	**3544**	F G H I J K	**3875**	B C D E F G H
Systhane 20EW (100g ai/ha)	**3717**	B C D E F G H I J	**3864**	B C D E F G H
Punch Xtra	**3560**	F G H I J K	**3846**	B C D E F G H
Propimax EC (190g ai/ha)	**3614**	D E F G H I J K	**3748**	B C D E F G H I
Systhane 20EW (125g ai/ha)	**3746**	B C D E F G H I J	**3727**	B C D E F G H I
Endura + Penetrator	**3337**	J K	**3678**	C D E F G H I
Dithane DF	**3365**	I J K	**3664**	C D E F G H I
Bravo 720 SC	**3251**	K	**3653**	D E F G H I
Plantvax 75 WP	**3380**	I J K	**3648**	D E F G H I
Procure 50 WS	**3455**	H I J K	**3627**	D E F G H I J
Quilt 200SE (14 oz/A)	**3540**	F G H I J K	**3500**	G H I J K
No fungicide control	**2648**	L	**2688**	L
Single application treatments[a]				
Quilt 200SE (20 oz/A) R1	**3233**	K		
Quilt 200SE 10.5 oz/A - 3 applications			**4102**	A B
Domark 230 ME (100g ai/ha) R1	**3512**	F G H I J K		
Domark 230 ME (100g ai/ha) R3			**3724**	B C D E F G H I
Application mean[b]	**3532** X		**3818** Y	

a. Fungicides applied once at growth stage R1 or R3, not in the 2 vs.3-application protocol.

b. Means separated using Students LSD (p=0.05), different letters indicate significant differences.

Table 7. Mean 1000 seed weights of the fungicides evaluated at the two locations in the 2003-04 Zimbabwe efficacy trials.

Fungicide treatments	Mean 1000 seed weights (g): Gwebi Variety Testing Center[b]	Mean 1000 seed weights (g): Rattray Arnold Research Station[b]
Quilt 200SE 10.5 oz/A - 3 applications	219 A B C	214 B C D
Echo 720,	213 B C D E	214 B C D
Eminent 125SL,	209 D E F G H I J K	211 C D E F G H I J
Domark 230 ME (115 g ai/ha)	209 D E F G H I J K	210 C D E F G H I J
Headline (BAS 500F)	220 A B	210 C D E F G H I J K
Domark 230 ME (100 g ai/ha)	214 B C D	210 C D E F G H I J K
Punch Xtra	204 G H I J K L M N	209 D E F G H I J K
Domark 230 ME (85 g ai/ha)	215 B C D	209 D E F G H I J K
Folicur 3.6 F	222 A	209 D E F G H I J K
Pristine (BAS 516F)	211 C D E F G H	208 D E F G H I J K L
Domark 230 ME (100 g/ha) R3[a]	212 C D E F	208 D E F G H I J K L
Systhane 20EW (125g ai/ha)	209 D E F G H I J K	205 F G H I J K L M N
Propimax EC (125g ai/ha)	208 D E F G H I J K L	203 K L M N O P Q R
Domark 230 ME (100 g ai/ha) R1[a]	209 D E F G H I J K	201 L M N O P Q R S
Quilt 200SE (14 oz/A)	203 J K L M N O P Q	201 L M N O P Q R S
Propimax EC (190g ai/ha)	212 C D E F G	198 N O P Q R S
Procure 50 WS	206 E F G H I J K L M	196 P Q R S
Quadris 2.08SC (6.2 oz/A)	211 C D E F G H I	196 Q R S
Systhane 20EW (100g ai/ha)	217 A B C	196 R S
Tilt 3.6EC (4 oz/A)	208 D E F G H I J K	196 R S
Plantvax 75 WP	199 M N O P Q R S	195 S T
Bravo 720 SC	204 I J K L M N O P	187 T U
Dithane DF	204 H I J K L M N O	187 U
Quilt 200SE (20 oz/A) R1 only[a]	203 J K L M N O P Q	176 V W
Endura + Penetrator	212 C D E F	173 V W
No-fungicide control	177 V	169 W
Location mean[b]	209 A	200 B

a. Fungicides applied once at growth stage R1 or R3; mean of 4 not 8 plots per location when 2 and 3 application treatments were combined for comparison between locations.

b. Means of the fungicides at both locations were separated using Students LSD (p=0.05); different letters indicate significant differences. The location interaction occurs where treatments have different letters at the two locations.

Table 8. Mean 1000 seed weights for each fungicide treatment when means are combined from the two locations of the 2003-04 Zimbabwe efficacy trials.

	Mean 1000 seed weights (g)			
Fungicides with 2 vs. 3 applications	**Mean of 2 applications[b]**		**Mean of 3 applications[b]**	
Headline (BAS 500F)	**209**	B C D E F G H I J	**221**	A
Folicur 3.6 F	**211**	B C D E F G H I	**221**	A
Echo 720,	**211**	B C D E F G H	**216**	A B C
Domark 230 ME (85g ai/ha)	**208**	D E F G H I J	**216**	A B C D
Pristine (BAS 516F)	**204**	H I J K L M	**215**	A B C D
Eminent 125SL,	**205**	H I J K L	**215**	A B C D E
Propimax EC (125g ai/ha)	**197**	M N O P	**214**	A B C D E F
Domark 230 ME (100g ai/ha)	**210**	B C D E F G H I	**214**	A B C D E F
Quadris 2.08SC (6.2 oz/A)	**194**	P Q	**213**	B C D E F
Domark 230 ME (115g ai/ha)	**207**	F G H I J	**212**	B C D E F G
Propimax EC (190g ai/ha)	**199**	K L M N O P	**211**	B C D E F G H
Punch Xtra	**203**	I J K L M N	**210**	B C D E F G H I
Systhane 20EW (125g ai/ha)	**204**	H I J K L	**210**	B C D E F G H I
Tilt 3.6EC (4 oz/A)	**195**	O P	**209**	C D E F G H I J
Quilt 200SE (14 oz/A)	**196**	N O P	**208**	D E F G H I J
Systhane 20EW (100g ai/ha)	**205**	G H I J K	**207**	E F G H I J
Procure 50 WS	**195**	O P	**207**	F G H I J
Bravo 720 SC	**187**	Q	**204**	H I J K L M
Dithane DF	**187**	Q	**204**	H I J K L M
Plantvax 75 WP	**192**	P Q	**202**	J K L M N O
Endura + Penetrator	**188**	Q	**197**	L M N O P
No fungicide control	**172**	R	**174**	R
Single application treatments[a]				
Quilt 200SE (20 oz/A) R1 only	**191**	P Q		
Quilt 200SE 10.5 oz/A - 3 applications			**216**	A B
Domark 230 ME (100g ai/ha) R1	**205**	O P		
Domark 230 ME (100g ai/ha) R3			**210**	F G H I J
Application mean[b]	**199** B		**209** A	

a. Fungicides applied once at growth stage R1 or R3, treatments not a 2 vs. 3-application comparison.
b. Means separated using Students LSD (p=0.05), different letters indicate significant differences.