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Fungicide performance on winter wheat

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CONTENTS

1.	ABSTRACT	1
2.	INTRODUCTION	3
3.	MATERIALS AND METHODS	4
3.1.	Experimental sites, cultivars and target diseases	4
3.2.	Site selection and establishment	5
3.3.	Experiment design	5
3.4.	Fungicide treatments	5
3.4.1.	Septoria tritici (sites 1, 2 and 3)	6
3.4.2.	Septoria tritici (Ireland) (Site 7)	7
3.4.3.	Yellow and brown rust (Sites 4 and 5)	7
3.4.4.	Mildew (Site 6)	8
3.5.	Assessments and records	10
3.5.1.	Assessments of leaf disease and green leaf area	10
3.5.2.	Assessment of ear diseases	10
3.5.3.	Assessment of stem-base diseases	10
3.5.4.	Lodging	10
3.5.5.	Yield	11
3.5.6.	Grain quality	11
3.5.7.	Agronomic records	11
3.6.	Data handling	11
3.7.	Statistical analysis	11
3.7.1.	Individual site, season and over year assessments	11
3.7.2.	Septoria tritici (Site 1) timing trial analysis	13
4.	RESULTS	13
4.1.	Septoria tritici experiments	13
4.1.1.	Disease control	13
4.1.2.	Yield	19
4.1.3.	T1 + T2 trial results	23
4.1.4.	Timing trial results	27

4.2.	Yellow rust experiments	28
4.2.1.	Disease control	28
4.2.2.	Yield	31
4.2.3.	T1 + T2 trial	35
4.3.	Brown rust experiments	37
4.3.1.	Disease control	37
4.3.2.	Yield	38
4.4.	Mildew experiments	39
5.	CONCLUSIONS	39
5.1.	Septoria tritici	39
5.2.	Yellow rust	41
5.3.	Brown rust	41
6.	REFERENCES	42
7.	ACKNOWLEDGEMENTS	42

1. Abstract

Between 2011 and 2014, the efficacy of new and existing fungicides was tested in 28 replicated trials in wheat across the UK and Ireland. Products were tested on the major foliar diseases of wheat, and each year there were 4 trials looking at *Septoria tritici*, and one trial of each targeting yellow rust, brown rust and mildew. The fungicides tested included new active ingredients from the succinate de-hydrogenase inhibitor (SDHI) group, the multi-site folpet, specific mildewicides and new mixtures of existing chemistry, tested alongside core treatments representing current standards. Some new fungicides tested have since been approved and are registered for use, whilst others are yet to be registered. The fungicides were tested by applying single applications at a range of rates ranging from quarter to double the full recommended label rate. Double dose treatments were included in the trials to accurately fit dose response curves (by better estimating the lower asymptote of the curve). Such doses are not legal for use in commercial crops. One of the *Septoria tritici* trials each year included a new trial design to investigate how the width of the effective spray window differs between fungicides. This was tested by applying half label rate treatments at one of 5 timings during the emergence of the final three leaves, with the efficacy on each leaf being assessed.

Straight products were tested in the trial series to investigate their efficacy, but in practice, fungicides at moderate or high risk of resistance, such as the azoles and the SDHIs, should always be applied in mixture with a partner of a different mode of action at a dose that will provide good efficacy on the target disease.

On *Septoria tritici*, Bravo (chlorothalonil) continued to provide effective protectant activity. Phoenix (folpet) also gave a useful level of protectant activity, although, when compared at equivalent proportions of label doses it was less effective than chlorothalonil. Products based on epoxiconazole and prothioconazole both gave a similar level of protectant and eradicant activity against *Septoria tritici*, although efficacy was lower than in previous seasons in both protectant and eradicant situations. The straight SDHI products Imtrex (fluxapyroxad) and Vertisan (penthiopyrad) had more effective protectant and eradicant activity against *Septoria tritici* than the azoles. Isopyrazam gave a similar level of protectant activity to Imtrex and Vertisan, but appeared to have less eradicant activity. The SDHI mixtures Aviator Xpro (prothioconazole + bixafen), Adexar (epoxiconazole + fluxapyroxad) and Vertisan + Ignite (penthiopyrad + epoxiconazole) all gave a higher level of protectant and eradicant activity than either the SDHI or azole components alone. Seguris (epoxiconazole + isopyrazam) gave a similar level of protectant activity to the other SDHI-azole mixtures, but appeared to have less eradicant activity. Results from the new trial design indicated that products may differ in their effective width of spray window. Significant differences between products were identified by the analysis. The spray window for the straight SDHI Imtrex was estimated to be wider than isopyrazam, and the spray window for the SDHI-azole mixtures

Aviator Xpro and Adexar estimated to be wider than Seguris. However, isopyrazam and Seguris were at least as effective as the other straight SDHI or mixture products, respectively, when applied at the optimum timing.

Powdery mildew was targeted at Fife for 4 seasons, and relied on natural infection to occur. Despite selection of the highly susceptible variety Claire, levels of powdery mildew were too low to permit assessment. These sites contributed data on *Septoria tritici* instead.

All products containing epoxiconazole (Ignite, Brutus, Seguris and Adexar) gave highly effective control of yellow rust, even at low doses. Proline (prothioconazole) and Comet (pyraclostrobin) also had good activity on yellow rust but were not as effective as epoxiconazole-based treatments. The straight SDHI products Imtrex and Vertisan had a useful level of activity against yellow rust, which could add to the control of yellow rust when used in mixtures. The SDHI-azole mixtures Adexar, Seguris and Vertisan + Ignite all gave effective control of yellow rust. In two of the four seasons reported here, Aviator Xpro gave less effective control of yellow rust compared to the other SDHI-azole mixtures tested.

Although only tested in one of the two brown rust trials reported here, the strobilurin Comet gave highly effective control of brown rust, even at low doses. The straight SDHIs Imtrex, Vertisan and isopyrazam gave effective control of brown rust. Ignite showed good activity against brown rust, and although not as effective as Comet, gave more effective control of brown rust than Proline. The SDHI-azole combinations Adexar, Aviator Xpro, Vertisan + Ignite and Seguris all gave very effective control of brown rust.

2. Introduction

Effective management of foliar disease is a key component of profitable wheat production. The last three leaves to emerge in a wheat crop contribute approximately 75% of the yield (AHDB, 2013) and so any loss of green leaf area to disease on these leaves is likely to have a significant negative impact on yield. Whilst cultural control methods such as crop rotation, delayed drilling and the use of resistant varieties can be employed to help manage disease levels in wheat crops, fungicides remain an important tool to help protect the crop.

The azole fungicides have a broad spectrum of activity and form the foundation of most fungicide programmes. However, the azole sensitivity of *Zymoseptoria tritici* (previously *Mycosphaerella graminicola*), the fungus causing Septoria tritici leaf blotch, has slowly declined over recent decades (Fraaije B.A, 2007; Cools H. J. et al., 2011). A number of new succinate dehydrogenase inhibitors (SDHIs) have been approved for use on wheat: bixafen, isopyrazam, fluxapyroxad and penthiopyrad. These new generation SDHIs have excellent activity on Septoria tritici and a broad spectrum of foliar disease control. However, they are at medium/high risk of resistance development and so should always be used in mixture with other actives of a different mode of action that are known to have efficacy on the target pathogen. Strobilurins still give useful control of rusts, and multi-sites, such as chlorothalonil or folpet, add useful protectant activity against Septoria tritici and reduce the risk of resistance development when used in mixture or sequence with other active groups.

Applying the appropriate fungicide products at the right time and correct dose is critical for effective disease control. Below the appropriate dose, profit is reduced by ineffective disease control. Applying rates above the appropriate dose is a waste of resources, increases the resistance risk, and in some cases could have negative environmental effects. The appropriate dose of fungicide changes little with wheat price but is more dependent on the disease risk and predicted yield loss, and is defined as the point where margin over the cost of fungicides is maximised. It is therefore important to assess the performance of individual fungicide active ingredients, and this can be effectively done by comparing dose-response curves.

This report provides a summary of the main findings from four years of fungicide performance experiments in harvest years 2011, 2012, 2013 and 2014. Dose response curves and graphs of protectant and eradicant activity show the activity of a range of fungicides against the major economic diseases in the UK. A full set of results can be found on the AHDB Cereals & Oilseeds website (cereals.ahdb.org.uk).

3. Materials and methods

3.1. Experimental sites, cultivars and target diseases

The experiments ran over four harvest years across the UK and Ireland to test fungicide performance against the four main foliar diseases of winter wheat – Septoria tritici (*Zymoseptoria tritici*), yellow rust (*Puccinia striiformis*), brown rust (*Puccinia triticina*), and powdery mildew (*Blumeria graminis*). There were seven sites each year, selected for high disease risk and using susceptible cultivars to create high disease pressure for one of these diseases (Table 1).

Table 1. Site numbers, locations, harvest years, cultivars and target diseases

Site number	Location	Harvest year	Cultivar	Target disease
1	Rosemaund, Herefordshire	2011	Ambrosia	Septoria tritici
2	Sutton Scotney, Hampshire	2011	KWS Sterling	Septoria tritici
3	Balgonie, Fife	2011	Consort	Septoria tritici
4	Terrington, Norfolk	2011	Robigus	Yellow rust
5	Girton, Cambridge	2011	Grafton	Brown rust
6	Balgonie, Fife	2011	Claire	Mildew
7	Carlow, Ireland	2011	Cordiale	Septoria tritici
8	Rosemaund, Herefordshire	2012	Consort	Septoria tritici
9	Sutton Scotney, Hampshire	2012	KWS Sterling	Septoria tritici
10	Balgonie, Fife	2012	Consort	Septoria tritici
11	Terrington, Norfolk	2012	Oakley	Yellow rust
12	Girton, Cambridge	2012	Grafton	Brown rust
13	Balgonie, Fife	2012	Claire	Mildew
14	Carlow, Ireland	2012	Cordiale	Septoria tritici
15	Rosemaund, Herefordshire	2013	Consort	Septoria tritici
16	Sutton Scotney, Hampshire	2013	KWS Sterling	Septoria tritici
17	Balgonie, Fife	2013	Consort	Septoria tritici
18	Terrington, Norfolk	2013	Oakley	Yellow rust
19	Girton, Cambridge	2013	Stigg	Brown rust
20	Balgonie, Fife	2013	Claire	Mildew
21	Carlow, Ireland	2013	Cordiale	Septoria tritici
22	Rosemaund, Herefordshire	2014	Consort	Septoria tritici
23	Sutton Scotney, Hampshire	2014	KWS Sterling	Septoria tritici
24	Balgonie, Fife	2014	Consort	Septoria tritici
25	Terrington, Norfolk	2014	Oakley	Yellow rust
26	Bar Hill, Cambridge	2014	Warrior	Brown rust
27	Balgonie, Fife	2014	Claire	Mildew
28	Carlow, Ireland	2014	Cordiale	Septoria tritici

Brown rust trials relied on natural infection up until 2013, subsequent trials were inoculated to ensure products were effectively tested. This was done by infecting pot-raised wheat of the same cultivar as the trial with a brown rust race suited to that cultivar. Three of the infected potted plants were evenly distributed and planted in each plot in April, and watered until they had established. All other trials relied on natural infection.

3.2. Site selection and establishment

Each of the trial sites had at least one year's break from wheat/barley to minimise the risk of take-all interfering with fungicide responses. Soil samples from each site were analysed for pH, major nutrients and soil texture.

Sites were selected to be at high risk of the target disease, and the trials were drilled at the appropriate seed rate for the locality and soil type using a suitable plot drill (e.g. Øyjord). The size of the plots in each trial were in the range of 20–60 m². Good farm practice was followed for all inputs (with the exception of fungicides) to ensure, as far as possible, that the trials were not affected by nutrient deficiencies or pest and weed infestations.

3.3. Experiment design

Standard randomisation of treatments within each replication was not considered suitable for trials of this size as it would leave them at risk of being affected by field variation. BIOS and AHDB Cereals & Oilseeds developed an incomplete block design in which each block contains only a selection of the treatments, but the blocks can be grouped together to form replicates, with each replicate containing all treatment combinations. Each trial incorporated between 9 and 67 treatments with three replicates.

3.4. Fungicide treatments

Fungicides were applied in 200 litres water/ha using pressurised hand-held plot spraying equipment. Flat fan nozzles were used with 200–300 kPa of pressure to produce a medium quality spray.

A variety of fungicides were tested to determine their effectiveness and dose response against the main foliar diseases, as well as their timing flexibility against *Septoria tritici* only. Most treatments were applied at quarter, half, full and double label recommended rates. Double dose treatments were used only to enable accurate dose-response curve fitting. These treatments are not permitted for farm crops and the grain was disposed of at harvest. Experimental fungicides not yet registered and approved for use were applied under an experimental permit.

The aim of the project was to test new active substances prior to their launch, and track the efficacy of actives currently registered for use. This was to provide growers and agronomists with the information to determine activity of products on the target pathogen and assist them in identifying the appropriate dose to use. However, in each season, the number of products that could be tested alongside core treatments was limited. Therefore, product selection for inclusion in the trials was prioritised in the following order:

1. Products containing a new broad-spectrum active substance
2. Products containing a new pathogen-specific active substance
3. Filling data 'gaps' for recently approved active substances, or recently approved new mixtures of existing active substances where data for particular diseases were inadequate
4. Products included for comparing older active substances against their baseline performance

Four sites were used annually to test *Septoria tritici* control and one site for each of the rusts and mildew. There were nine *Septoria tritici* trials across these sites in 2011 and six trials in the following 3 years, and two yellow rust, two brown rust and two mildew trials in 2011 which was reduced to one each for 2012, 2013 and 2014 (Table 4).

In 2011, sites tested each product at 0.5 of label rates applied at T1 and T2 as a separate additional trial. This was discontinued after 2011, following a review of the value of this information, in preference for increasing the number of products tested within the dose response trials.

3.4.1. *Septoria tritici* (sites 1, 2 and 3)

Dose response trials

At sites 2 and 3, two trials were set up and repeated at the two sites (four trials in total). Trial 1 tested the effectiveness of fungicides and doses (quarter, half, full and double label rate) at T2 (GS39), and trial 2 tested the same products and doses at T1 (GS32). Bravo was applied in both trials at half rate only as a standard to compare with the other treatments. At site 1, one trial was set up testing the same products and doses applied when leaf 2 was fully emerged (GS37).

Flexibility of timing trials

To provide additional information on product timing flexibility, a new design has been tested at one site in Herefordshire in each of the four years. In addition to measuring a full set of dose response curves, it evaluates a range of spray timings (providing eradicant and protectant information to define the spray window) at one dose. This aims to provide comparative 'spray window' information for new fungicides.

Half doses of each product were applied at one of five different timings from approximately growth stage GS31 to GS55:

Target timings used:

- 2–4 weeks prior to leaf 2 emergence,
- 1–2 weeks prior to leaf 2 emergence,
- Leaf 2 emergence,
- 1–2 weeks post leaf 2 emergence
- 2–4 weeks after leaf 2 emergence.

In addition, the date of leaf emergence was monitored and recorded for the top 3 leaves (Table 2). Disease assessments were conducted at 3 weeks, and 4–6 weeks after the main GS37 timing, with the exact timing of this second assessment being adjusted according to the rate of disease progress in each season. The dose response treatments were applied at either quarter, half, full or double dose at leaf two emergence. Adjustments in the targeted treatment timings in each year were made over the 4 years to improve the range of spray timings either side of leaf 2 emergence. This is reflected in the actual timings (Table 3).

Table 2. Leaf emergence dates at site 1, in each of the 4 seasons

Date of leaf emergence	2011	2012	2013	2014
Leaf 3	01-May	25-Apr	07-May	28-Apr
Leaf 2	09-May	14-May	20-May	15-May
Leaf 1	16-May	21-May	29-May	26-May

Table 3. Treatment timings at site 1 in each of the 4 seasons

Treatment timing	2011	2012	2013	2014
Timing 1	16-Apr	16-Apr	25-Apr	10-Apr
Timing 2	28-Apr	25-Apr	13-May	24-Apr
Timing 3	09-May	12-May	18-May	15-May
Timing 4	19-May	23-May	31-May	30-May
Timing 5	31-May	01-Jun	07-Jun	05-Jun

3.4.2. *Septoria tritici* (Ireland) (Site 7)

The same treatments as at sites 2 and 3 were applied, plus some additional treatments were tested against *Septoria tritici* in Ireland. Each treatment was applied at GS39 at quarter, half, full and double label rate, with the exception of Bravo, which was only applied at half rate as a standard.

3.4.3. Yellow and brown rust (Sites 4 and 5)

Identical treatments and doses (quarter, half, full and double rate) were tested at these sites but on different target diseases and at different timings. Site 4 in Norfolk looked at the effects on yellow

rust applied at GS32, and site 5 in Cambridgeshire tested effectiveness on brown rust applied at GS39.

3.4.4. Mildew (Site 6)

Fife tested a treatment list which included specific mildewicides against powdery mildew at quarter, half, full and double label dose. The treatments were applied at T1.

All sites except site 1 hosted an additional trial design in 2011 against the relevant target disease for the site. In this design, repeat applications were carried out at T1 and T2 using half label recommended dose (Table 4).

Table 4. Site locations and trial design in each year

Site	Year	Number and type of trial
1 (Hereford) Septoria tritici	2011	T1 + T2
		New design – 5 timings
	2012	New design – 5 timings
	2013	New design – 5 timings
2 and 3 (Hampshire and Fife) Septoria tritici	2011	New design – 5 timings
		T1 + T2
		T1 timing
	2012	T2 timing
		T1 timing
	2013	T2 timing
		T1 timing
	2014	T2 timing
		T1 timing
4 (Norfolk) Yellow rust	2011	T1 + T2
		T1 timing
	2012	T1 timing
	2013	T1 timing
5 (Cambridge) Brown rust	2011	T1 timing
		T2 timing
	2012	T1 + T2
	2013	T2 timing
6 (Fife) Powdery mildew	2011	T2 timing
		T1 + T2
	2012	T1 timing
	2013	T1 timing
7 (Carlow) Septoria tritici	2011	T1 timing
		T2 timing
	2012	T1 + T2
	2013	T2 timing
	2014	T2 timing
		T1 timing

Where a new active substance was only available commercially as a formulated mixture, the relevant mixture partner/s were also included in the trials. Spectrum of activity was used to determine the target diseases (and hence trial sites/varieties) against which each new product should be tested.

Fungicides tested included a range of existing products that were commercially available and those in development and planned for registration. Since the start of the project, the products Adexar (fluxapyroxad + epoxiconazole) and Imtrex (fluxapyroxad) from BASF, and Vertisan (penthiopyrad) from DuPont have become commercially available. Brutus was only tested in 2011, and Opus was replaced with Ignite or Opus Max from 2012. Aviator Xpro tested in all UK trials contained prothioconazole 160g/l and bixafen 75g/l (Aviator 235 Xpro), whilst the product registered and used in Ireland was Aviator Xpro 225 which contained a slightly lower loading of prothioconazole (prothioconazole 150g/l + bixafen 75g/l).

Fungicide doses stated in this report are all expressed as a proportion of full label rates. Full label rates for each product tested are given in Table 5.

Table 5. Full label rates l/ha, and active substance g/ha, for products tested for the control of one or more diseases between 2011 and 2014.

Product tested	Full label dose l/ha	Active ingredient (a.i.) g/ha at full label rate
Adexar	2	Epoxiconazole 125g + fluxapyroxad 125g
Aviator 225Xpro	1.25	Prothioconazole 187.5g/ + bixafen 93.75g
Aviator235Xpro	1.25	Prothioconazole 200g + bixafen 93.75g
Bravo	2	Chlorothalonil 1000g
Brutus / Gleam	3	Epoxiconazole 112.5 + metconazole 82.5 g
Caramba	1	Metconazole 90g
Comet 200	1.25	Pyraclostrobin 250g
Corbel	1	Fenpropimorph 750g
Cyflamid	0.5	Cyflufenamid 25g
Flexity	0.5	Metrafenone 150g
Ignite / Opus max	1.5	Epoxiconazole 124.5g
Imtrex	2	Fluxapyroxad 125 g
Opus	1	Epoxiconazole 125g
Phoenix	1.5	Folpet 750g
Proline / Proline275*	0.80 / 0.72	Prothioconazole 200g /198g
Prosaro	1.2	Prothioconazole 150g and tebuconazole 150g
Seguris	1	Epoxiconazole 90g + isopyrazam 125g
Talius	0.25	Proquinazid 50g
Tern	1	Fenpropidin 750g
Treoris	2.5	Chlorothalonil 631.25 + penthiopyrad 251.25g
Vertisan	1.5	Penthiopyrad 300g

*Proline and Proline275 were considered equal as they both delivered similar loading of a.s. at full label rate. This was a concentration rather than a formulation change.

**Ignite and Opus Max are new EC formulations of epoxiconazole.

3.5. Assessments and records

3.5.1. Assessments of leaf disease and green leaf area

Foliar disease assessments were carried out by randomly selecting tillers and estimating the percent surface area of each leaf affected by disease (including any necrosis and chlorosis associated with the disease) and the percentage of green area.

Twenty five shoots from across untreated areas were assessed at each application to establish background disease levels. Plot assessments, on ten randomly selected but representative tillers, began approximately 3 weeks after treatments were applied. For applications at T1, the first assessment was made at T2. Assessments were then made 3 and 6 weeks after T2 to catch disease expression on eventual leaf 3 approximately 3 weeks after T2, and leaf 2 and the flag leaf approximately 6 weeks after T2. The exact timing of each assessment was decided by site managers locally to capture the best disease development and, in the case of the last assessment, before the untreated plots senesced. Plot assessments for the multi-timing trial in Herefordshire started when the third application was applied, when the plots that had been sprayed two and four weeks previous were assessed. Subsequent assessments followed at 3 and 6 weeks after the 3rd spray timing.

3.5.2. Assessment of ear diseases

Ten ears from each untreated plot were assessed for disease at GS85. A full assessment of ten ears from every plot followed if more than 10% untreated ear area was affected by a particular disease. These were based on the percentage ear area infected with disease.

3.5.3. Assessment of stem-base diseases

Stem-base diseases were recorded on 25 randomly selected shoots at GS31-32 before any treatments had been applied. Incidence was recorded for any disease found and a severity score given for eyespot if seen. Stem disease was assessed again at GS75 by selecting 25 plants in every untreated plot and categorising any lesions into slight (lesion girdling less than half the circumference of the stem), moderate (lesion girdling more than half the circumference of the stem) or severe (lesion girdling more than half the circumference of the stem, with the tissues softened so that lodging would occur). A full assessment of all plots followed if over 25% of stems had moderate or severe lesions or 10% had severe lesions of any disease. Assessment data was used to calculate the incidence of disease, and a disease severity index.

3.5.4. Lodging

Plots were assessed for lodging prior to harvest. The percent area affected was recorded if lodging was present.

3.5.5. Yield

All plots were harvested using a plot combine harvester. Grain samples were taken to determine moisture content and for grain quality assessments. Yields were calculated at 85% dry matter.

3.5.6. Grain quality

Specific weight of grain was measured for each plot and adjusted to 85% dry matter.

3.5.7. Agronomic records

Details of site, soil type, previous rotation and all agrochemical inputs were recorded.

3.6. Data handling

Disease, green leaf area, yield and grain quality data were collected manually or directly onto portable data devices. All data were transferred to Microsoft Excel worksheets after collection.

3.7. Statistical analysis

3.7.1. Individual site, season and over year assessments

For all sites and seasons, each assessment of disease by leaf layer, and yield, was summarised using a linear mixed model employing the residual maximum likelihood (REML) approach, with the validity of the analysis being checked by the examination of residuals. The method is appropriate for analysis of individual trials employing an incomplete block design and over trial and over year analyses. In over trial and over year analyses, the REML method has the advantage of including information on product differences that may be available in site and year means and of calculating the appropriate weight to give this information in the combined means. Additionally the method is suitable for use with an incomplete data matrix, for instance where some products are not included in all years or trials. In over trial and over year analyses, REML means are always between the individual site means and the combined means. If the variability between sites was small relative to the variation within sites, REML means would be close to the unadjusted means.

REML analysis is sensitive to the proportion of the data matrix that is missing. Although it is theoretically possible to include all the data from individual assessment dates and leaf layers at each site, the resulting matrix is sparse and investigation has shown that the method does not converge to give a solution. The average percentage disease was calculated from the leaves categorised as showing eradicant, protectant or mixed activity at each site. The categorisation criteria are described below. This provided a suitable measure of disease for combining over

experiments using the REML method. Exponential curves were fitted to the REML adjusted means to provide over-site means and season summaries.

For each disease assessment, dose response curves were plotted for each fungicide. Exponential curves of the form $y = a + be^{kx}$ were fitted, where y = % disease and x = proportion of the recommended dose. Exponential curves were also fitted to the green leaf area, yield and specific weight data. All curves were constrained to pass through the mean of the untreated (dose = 0) plots.

Variables that did not contribute useful or reliable information were excluded from further analysis. This was considered on a site by site basis, as a guide, data were excluded where there was no significant effect of treatment, and where there was an average of less than 3% or more than 70% disease on untreated plots. In addition, assessments where more than one disease was recorded on a particular date were examined to determine if results for either disease were compromised by an interaction. Any assessments thought to be compromised were excluded from the analysis. For each site, the mean disease and green leaf area were calculated, based on the categorisation of leaf layers as indicating eradicant, protectant or mixed activity from the fungicide. This was based on leaf emergence relative to spray timing and, in the case of *Septoria tritici*, chlorothalonil (Bravo), a fungicide known to have only protectant activity, was used as a check. For *Septoria tritici*, means were calculated separately for protectant fungicide activity (leaves just emerged, or still to emerge at time of treatment), and eradicant fungicide activity (the first two non-protectant leaves down the stem). For other pathogens, which have shorter latent periods (and hence shorter eradicant periods) than *Zymoseptoria tritici*, the eradicant and protectant categories were combined.

Each season, results from all sites were combined to provide an across-site mean for disease and yield. Analysis from previous fungicide performance projects (Bounds *et al.*, 2012) has shown that, whilst no transformation is needed for yield or specific weight, a logit transformation of % disease and % green leaf area provides a more valid analysis. Therefore, disease and green leaf area were analysed on a logit scale and back-transformed for ease of evaluation. This process provided a more equal weighting between sites.

Various statistical methods have been investigated which could, theoretically, be used as a guide to whether dose-response curves differ between products. The methods are of varying complexity, they generally require some statistical knowledge to interpret, and all methods for estimating confidence intervals around non-linear fits depend on certain statistical assumptions – there is no simple ‘perfect’ method. Comparisons between these statistical methods and a simpler interpretation has shown that the following is a good practical guide: The distance between the mean data points (shown on the charts at each tested dose) and the fitted curve provides a good

guide to the reliability of the fit. Curves which lie on, or close to, the data points to which they were fitted, are more reliable than curves where the data points lie scattered some distance on either side of the curve. Comparing any two curves, if the data points for the curves do not overlap, at each respective dose, then there is a high probability that the fitted curves differ.

3.7.2. *Septoria tritici* (Site 1) timing trial analysis

In each season, *Septoria tritici* efficacy values for each leaf were converted into % control. For each leaf, the time of leaf emergence was compared with the five application timings, to allow curve fitting. Data from each leaf layer was then combined to create a single response to indicate how % control varied with applications before, at, and after the point of leaf emergence. The shape of the response curve of efficacy on the spray timing is represented by the following equation:

$$b(t) = \theta e^{\left(\frac{-(t-\mu)^2}{2\sigma^2}\right)}$$

Equation 1 (shown above) was used to describe the shape of the spray timing x efficacy response curve used to generate the curves shown in Figure 21, where t is spray time, μ (μ) is the spray time with maximum effect, θ (θ) describes the maximum control at spray time μ , and σ (σ) describes the width of the spray window. Varying σ by product was shown to significantly increase the efficacy variation accounted for. The appropriateness of equation 1 to represent the relationship of efficacy on spray timing has been peer reviewed and published previously (Paveley *et al.*, 2000).

4. Results

4.1. *Septoria tritici* experiments

4.1.1. Disease control

In 2011, there was moderate *Septoria tritici* pressure at all sites. The azole standards Proline or Proline 275 (prothioconazole), Opus (epoxiconazole SC) or Ignite (epoxiconazole EC) were similar in their protectant and eradicant activity (Figures 1 and 2). Brutus (epoxiconazole + metconazole) gave a higher level of protectant activity than Proline, Opus or Ignite, and appeared to give a higher level of eradicant activity at higher doses. The straight SDHI isopyrazam gave a higher level of protectant activity than Proline, Opus or Ignite, but gave similar eradicant activity. Bravo (chlorothalonil) provided useful protection, with half dose giving a similar level of protection to a half dose of Brutus or isopyrazam. The SDHI-azole mixtures Aviator Xpro (prothioconazole + bixafen), Adexar (epoxiconazole + fluxapyroxad) and Seguris (epoxiconazole + isopyrazam), all gave more effective protectant activity against *Septoria tritici* than the azole standards Proline, Opus and Ignite. This indicates that the SDHI component was adding significantly to the protectant activity of prothioconazole/epoxiconazole. At half dose and below, Adexar appeared to give a higher level of

protectant activity than Aviator Xpro. Aviator Xpro and Adexar gave a higher level of eradicant activity than the azoles, and when compared at equivalent proportions of label rate, Adexar appeared slightly more effective than Aviator Xpro. Seguris appeared more comparable with Adexar and Aviator in protectant activity than in eradicant.

In 2012, favourable conditions for *Septoria tritici* resulted in high disease pressure in all trials. Ignite and Proline were again equal in their protectant and eradicant activity (Figures 3 and 4). Phoenix (folpet) gave a useful level of protectant activity, although was not as effective as Ignite or Proline. When compared at half label rates Bravo gave a higher level of protectant activity than Phoenix, Ignite or Proline. The straight SDHI products Imtrex (fluxapyroxad) and isopyrazam (not launched as straight on wheat) both gave similar protectant activity and were more effective than Ignite, Proline or Phoenix, and of the two, Imtrex appeared to have greater eradicant activity. The SDHI-azole mixtures Adexar, Aviator Xpro and Vertisan (penthiopyrad) + Ignite all gave a higher level of protectant and eradicant activity than the azole or solo SDHI products. Seguris gave a similar level of protectant activity to Adexar, Aviator Xpro and Vertisan + Ignite, although did not give such effective eradicant activity.

In 2013, a period of dry spring weather resulted in lower *Septoria tritici* pressure. Ignite and Proline gave a similar level of protectant activity, and Phoenix also gave a useful level of protectant activity (Figure 5). The straight SDHI products Imtrex and Vertisan were highly effective in protectant situations against *Septoria tritici*. A half dose of Bravo gave a higher level of protectant activity than Ignite, Proline and Phoenix, and was similar to Imtrex and Vertisan. The SDHI-azole mixtures Adexar, Aviator Xpro and Vertisan + Ignite all gave a high level of protectant activity. Due to the dry spring conditions, the 2013 season information on the eradicant activity of products was limited, and is based on a single site so should be treated with caution, but was consistent with previous observations. Imtrex, Adexar, Aviator Xpro and Vertisan + Ignite, all gave a higher level of eradicant activity than the straight azole products.

Due to higher than average rainfall and mild winter and spring weather, *Septoria tritici* pressure was very high in most parts of the UK and Ireland in 2014, providing an extreme test of protectant and eradicant activity. Phoenix showed a useful level of protectant activity, although half dose Bravo was more effective as a protectant than half dose Phoenix, Ignite or Proline (Figure 6). Proline appeared to give more effective protectant activity than Ignite, although they gave identical eradicant activity (Figures 6 and 7). The lack of any consistent differences between Proline and Ignite in eradicant or protectant situations in previous years means that this result would require confirmation in subsequent seasons prior to any conclusion being drawn. The straight SDHI products Imtrex and Vertisan gave more effective protectant and curative activity than the azoles. The SDHI-azole mixtures Adexar, Aviator Xpro and Vertisan + Ignite all gave more effective

protectant and eradicant activity against *Septoria tritici* than either the straight SDHI or straight azole products. There were no differences between any of the SDHI-azole mixtures in terms of protectant or eradicant activity.

Analysis over the four years showed that Ignite and Proline gave a similar level of protectant and eradicant activity (Figures 8 and 9). Half dose Bravo gave a higher level of protectant activity than Ignite or Proline. Phoenix also gave useful protectant activity although, at half dose, it was not as effective as Bravo. The straight SDHI Imtrex gave a higher level of both protectant and eradicant activity than Ignite or Proline. The SDHI-azole mixtures Aviator Xpro, Adexar and Vertisan + Ignite all gave a higher level of protectant and eradicant activity than the straight azole or straight SDHI products. Aviator Xpro, Adexar and Vertisan + Ignite all gave very similar protectant and eradicant activity.

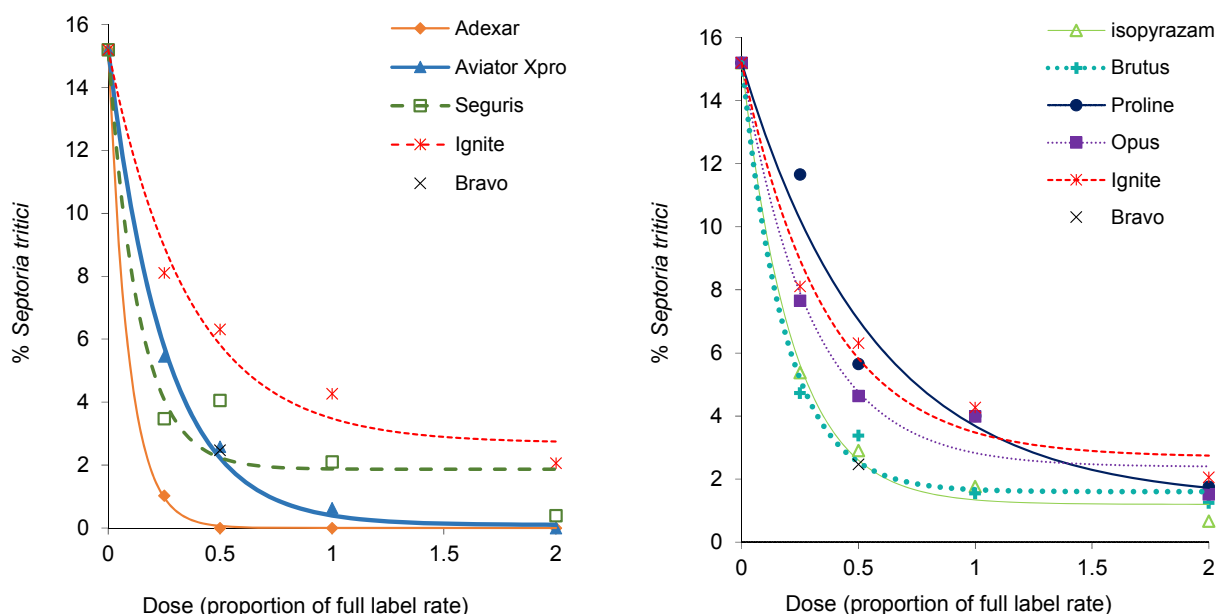


Figure 1. Fungicide dose-response curves for protectant activity against *Septoria tritici* in 2011 (overall means across sites 2, 3 and 7). The product curves have been separated into two for clarity. Ignite is repeated on both graphs as a point of comparison.

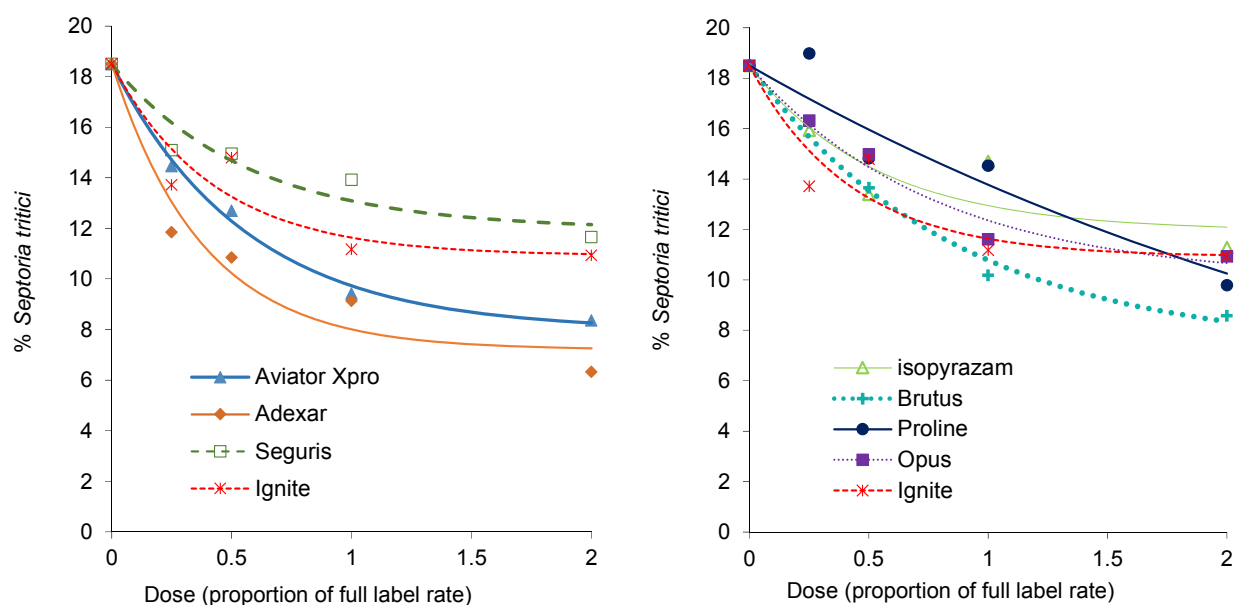


Figure 2. Fungicide dose response curves for eradicator activity against *Septoria tritici* in 2011 (overall means across sites 2, 3 and 7)

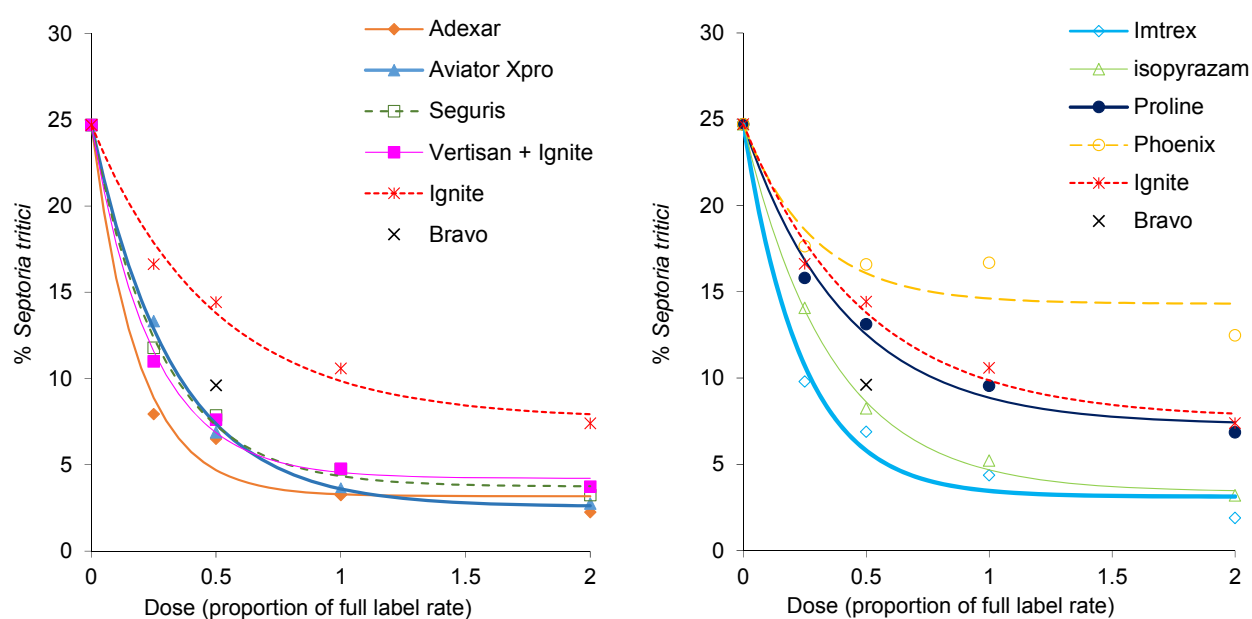


Figure 3. Fungicide dose-response curves for protectant activity against *Septoria tritici* in 2012 (overall means across sites 8, 9, 10 and 14)

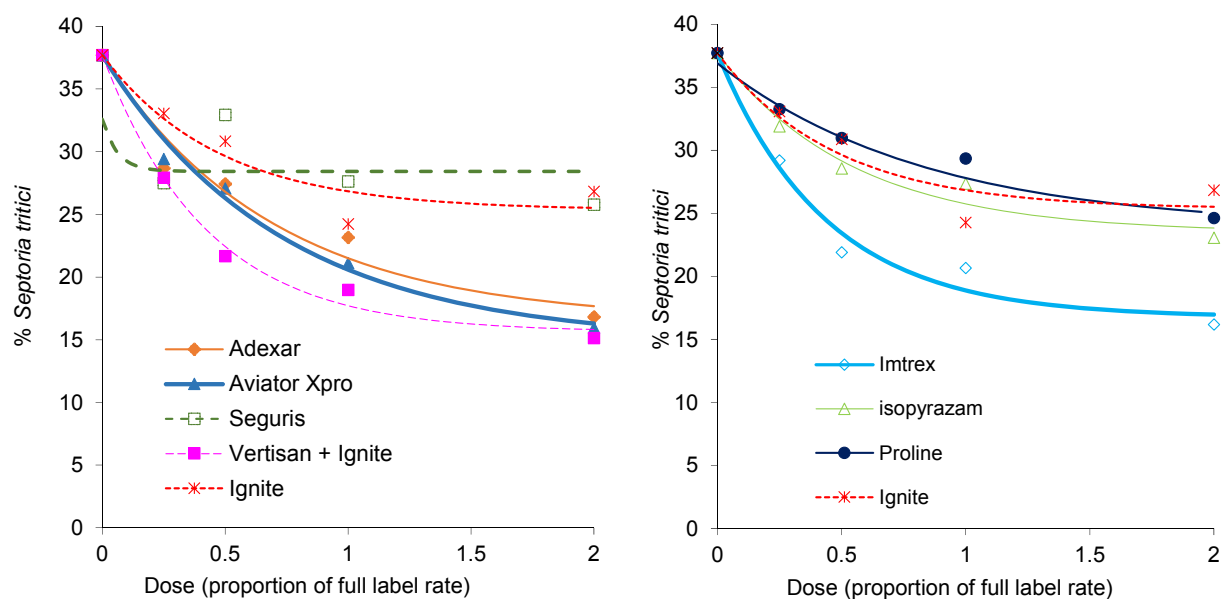


Figure 4. Fungicide dose response curves for eradicant activity against *Septoria tritici* in 2012 (overall means across sites 9, 12 and 13)

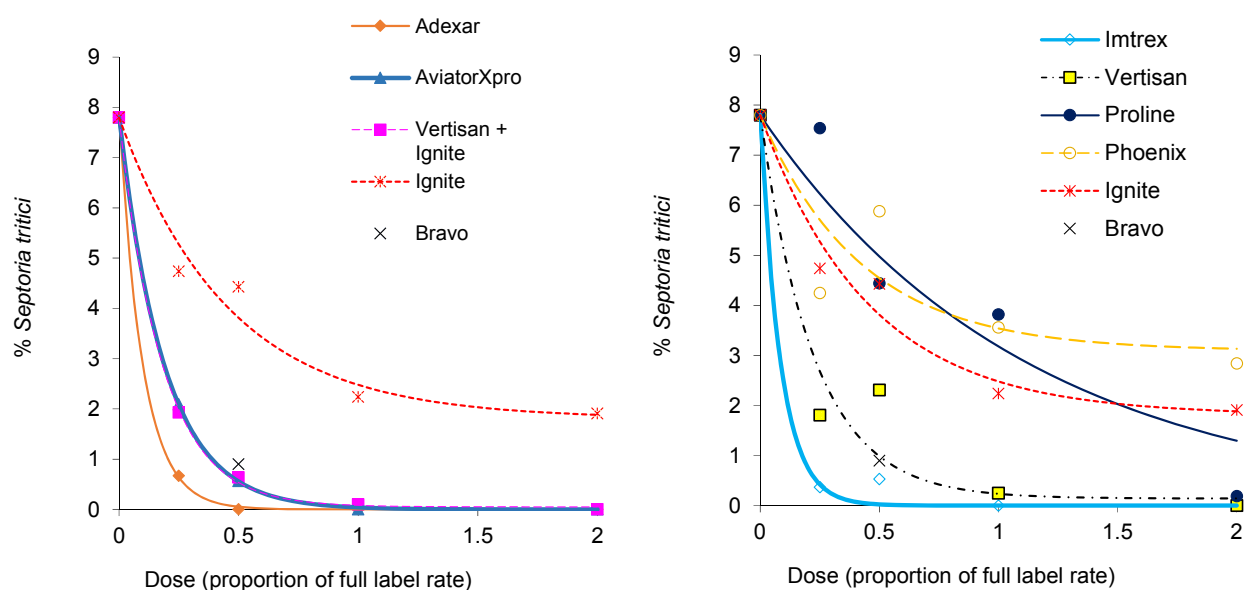


Figure 5. Fungicide dose-response curves for protectant activity against *Septoria tritici* in 2013 (overall means across sites 15, 16, 17, 18 and 20)

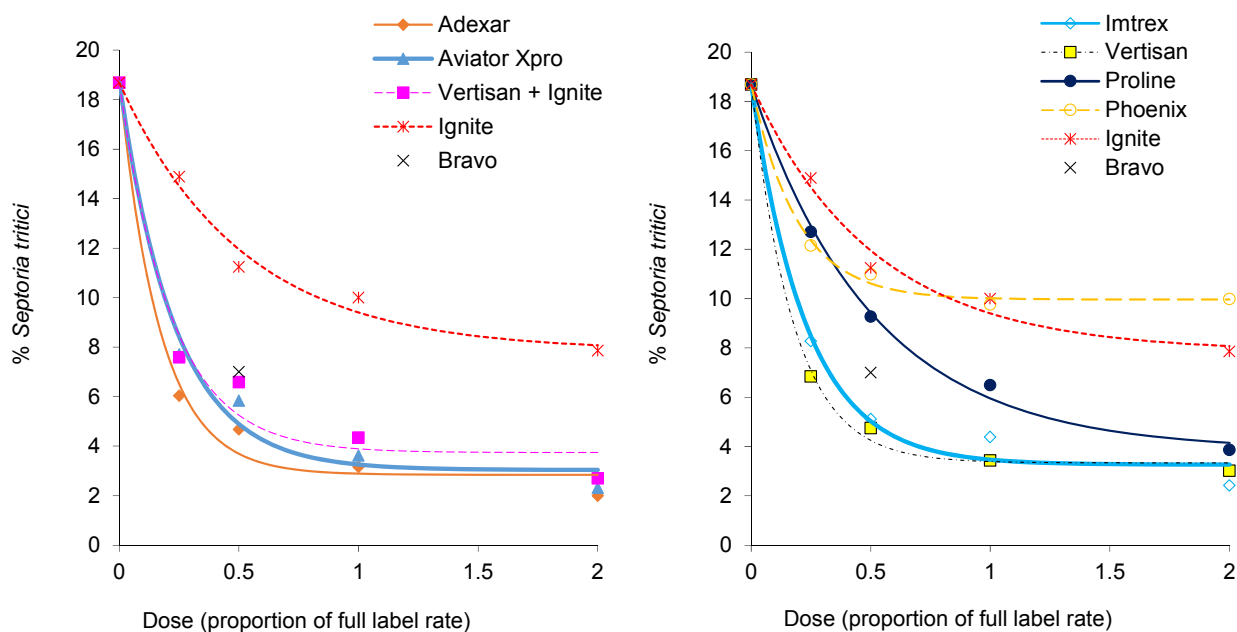


Figure 6. Fungicide dose-response curves for protectant activity against *Septoria tritici* in 2014 (overall means across sites 22, 23, 24, 27 and 28)

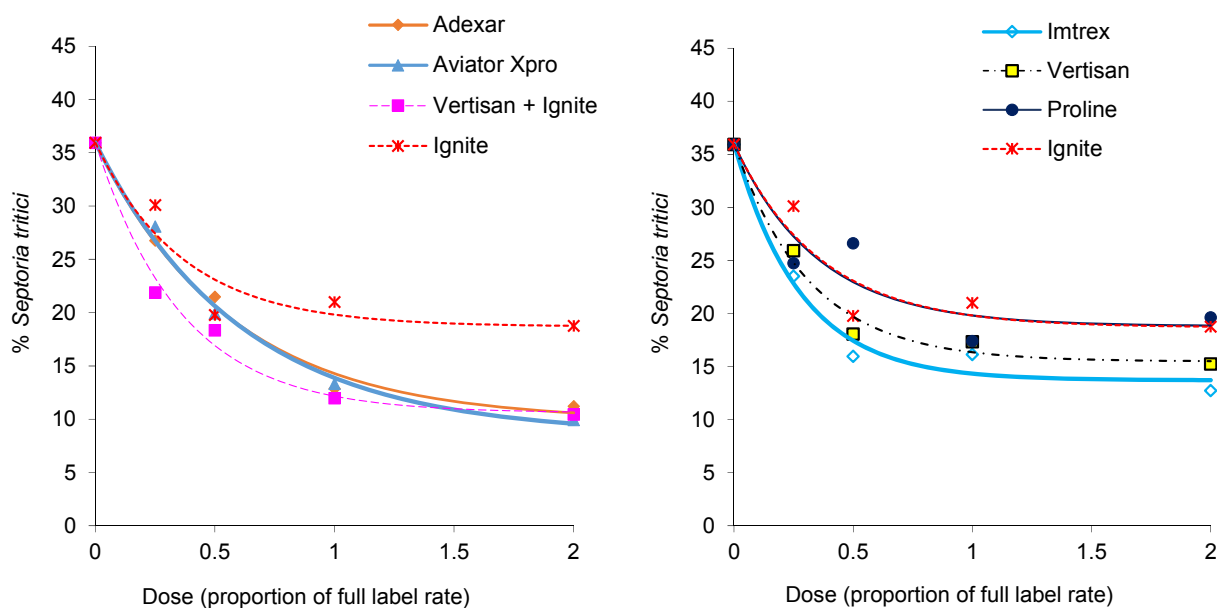


Figure 7. Fungicide dose response curves for eradicant activity against *Septoria tritici* in 2014 (overall means across sites 23, 24 and 27)

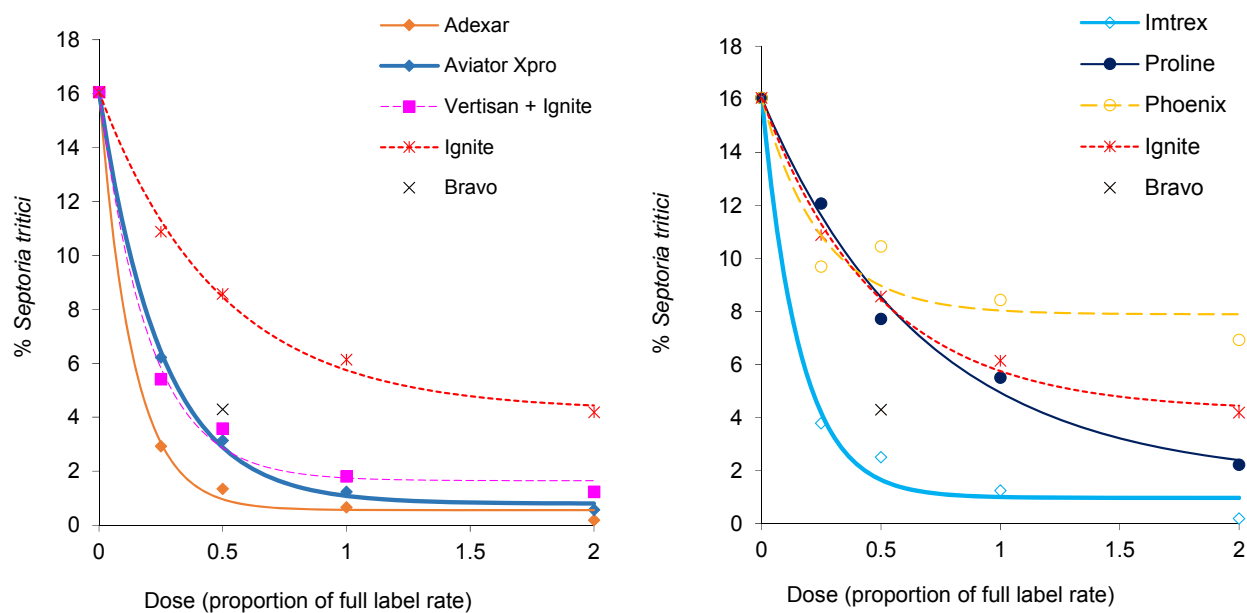


Figure 8. Fungicide dose-response curves for protectant activity against *Septoria tritici*; 2011-2014 (overall means across sites 2, 3, 7, 8, 9, 10, 14, 15, 16, 17, 18, 20, 22, 23, 24, 27 and 28)

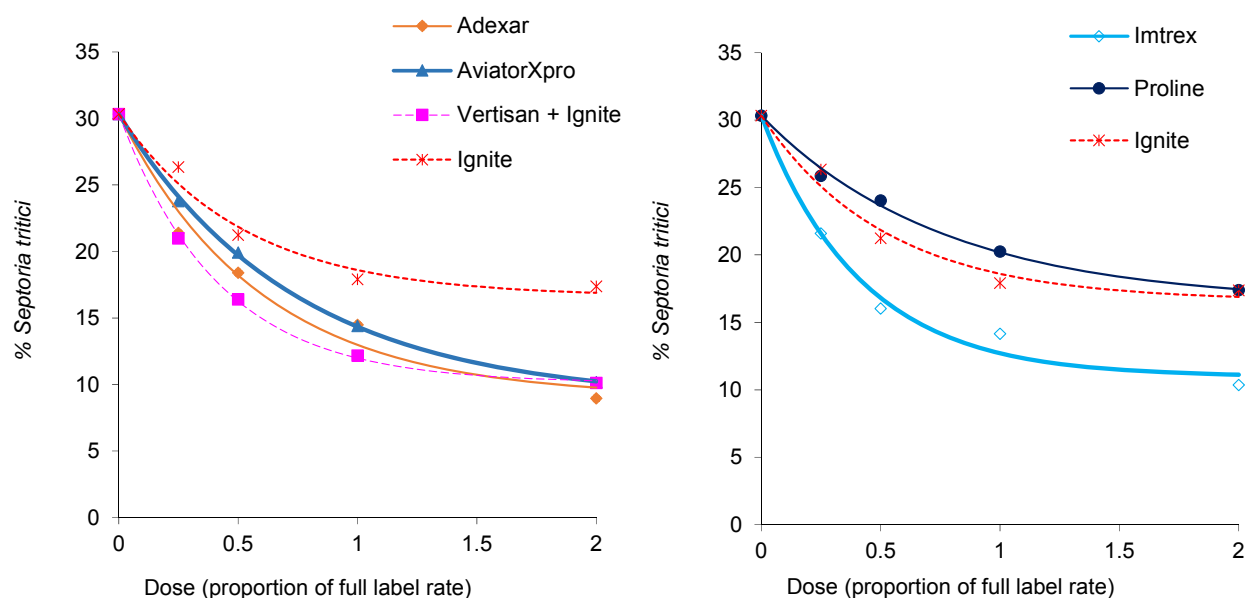


Figure 9. Fungicide dose-response curves for eradican activity against *Septoria tritici*; 2011-2014 (overall means across sites 2, 3, 7, 9, 12, 13, 17, 23, 24 and 27)

4.1.2. Yield

Commercial wheat disease control strategies generally involve between two and four fungicide application timings, with products often being applied in mixtures. Yield responses to single spray applications, which do not fully control disease, will not reflect yield responses that will be seen in practice where a more comprehensive strategy is employed. However, yield response data can

support disease control information on products, and can identify effects on yield that may not be attributable to disease control alone.

In 2011, maximum yield responses to fungicides from single spray applications at individual sites ranged from 2.5t/ha to 3.5t/ha, reflecting the differences in disease pressure observed. On average across these sites, yield increases from applying a single full dose ranged from 1.0 t/ha to 2.0t/ha (Figure 10). Opus, Proline and Ignite all gave a similar yield response at full dose (1.06, 1.22 and 1.05 tonnes/ha, respectively). Isopyrazam and Brutus appeared to give a slightly higher yield response at full dose than the azoles (1.44 tonnes/ha for both). The SDHI-azole mixtures Adexar, Aviator Xpro and Seguris gave a higher yield at full dose than the solo SDHI or azole components (2.02 tonnes/ha, 1.95 tonnes/ha and 1.53 tonnes/ha, respectively). Adexar and Aviator Xpro gave a similar yield response at full dose, and this appeared to be slightly higher than full rate Seguris. When compared at quarter and half dose, Adexar appeared to give a slightly higher yield than Aviator Xpro.

Yields in 2012 were low due to dull conditions during grain filling (DEFRA, 2013), however the range of yield responses to fungicides from single spray applications at individual sites ranged from 1.0t/ha to 4.4t/ha, reflecting the high disease pressure observed. On average across these sites yield responses were slightly lower than in 2011, ranging from 0.38 tonnes/ha to 1.51 tonnes/ha (Figure 11). Applied at full dose, Ignite and Proline gave similar yield responses of 0.75 tonnes/ha and 0.58 tonnes/ha, respectively, with Phoenix giving a slightly lower yield response of 0.38 tonnes/ha. The straight SDHI products Imtrex and isopyrazam gave a slightly higher yield response (1.22 and 1.11 tonnes/ha), and the SDHI-azole combinations Adexar, Aviator and Vertisan + Ignite gave a higher yield response than any of the solo SDHI or azole products (1.51, 1.39 and 1.28 tonnes/ha, respectively). The yield response for full rate Seguris (0.99 tonnes/ha) was similar to the yield response from isopyrazam (1.11t/ha).

Due to low levels of *Septoria tritici*, yield responses to fungicides were low in 2013. At all sites the maximum response was less than 0.6t/ha, and on average across all sites it ranged from 0.09 tonnes/ha to 0.39 tonnes/ha (Figure 12). In line with the disease control data, Ignite and Proline gave a similar yield response, the straight SDHIs Imtrex and Vertisan gave a slight increase in yield over the azoles, and the SDHI-azole mixtures Adexar and Aviator Xpro gave a further slight increase in yield.

In 2014, severe *Septoria tritici* pressure led to some large yield responses from fungicide treatment. Maximum yield responses to fungicides from single spray applications at individual sites ranged from 1.6t/ha to 4.4t/ha, reflecting the high pressure, and differences in disease pressure observed. Averaged across the sites, yield increases from full dose applications ranged from

0.39 tonnes/ha to 2.36 tonnes/ha (Figure 13). At full dose, Phoenix and Ignite gave a similar yield response of 0.39 and 0.42 tonnes/ha, respectively, whilst Proline gave a higher yield response of 1.16 tonnes/ha. The straight SDHI products Vertisan and Imtrex gave a higher yield response than Proline (1.64 and 2.36 tonnes/ha, respectively). The three SDHI-azole mixtures generally gave a larger yield response than the solo products. Vertisan + Ignite gave a slightly lower yield response (1.75 tonnes/ha) than Aviator Xpro (2.33 tonnes/ha) or Adexar (2.36 tonnes/ha).

Mean yield data for the *Septoria tritici* sites over all four years showed that yield increases from full dose applications ranged from 0.4 tonnes/ha (Phoenix) to 1.55 tonnes/ha (Adexar) (Figure 14). Ignite and Proline both gave a similar yield response of 0.57 tonnes/ha and 0.8 tonnes/ha, respectively. Imtrex gave a higher yield than the azoles, with a yield response of 1.39 tonnes/ha. The SDHI-azole mixtures Vertisan + Ignite, Aviator Xpro and Adexar generally gave larger yield responses than either the SDHI or azole components alone (1.18, 1.47 and 1.55 tonnes/ha, respectively).

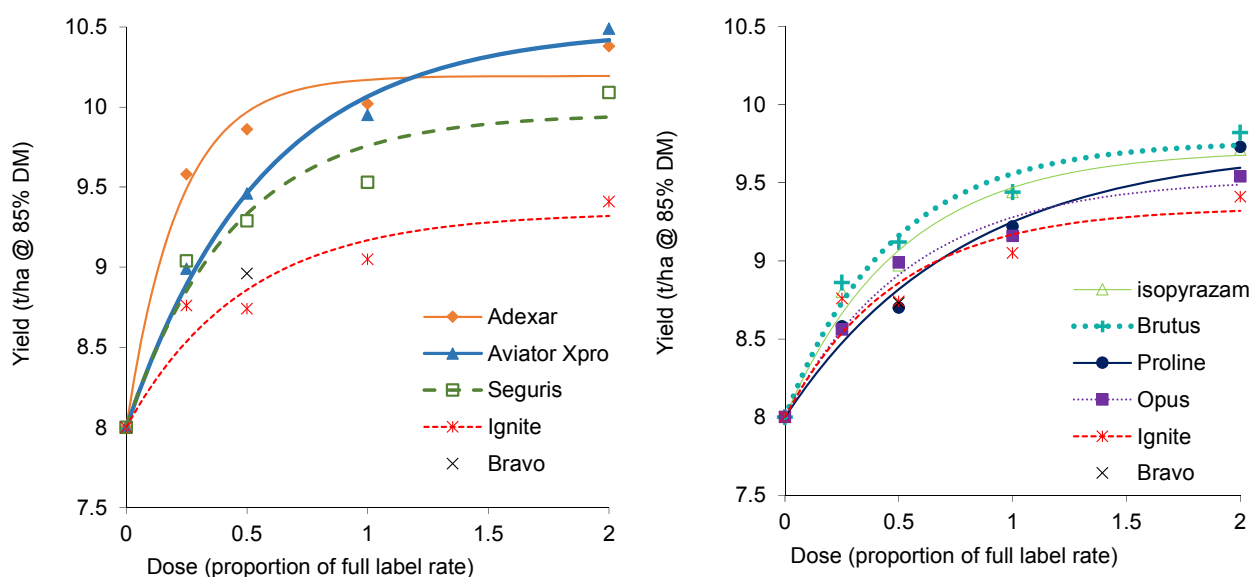


Figure 10. Fungicide dose response curves for yield in *Septoria tritici* trials in 2011 (overall means across sites 1, 2, 3 and 7)

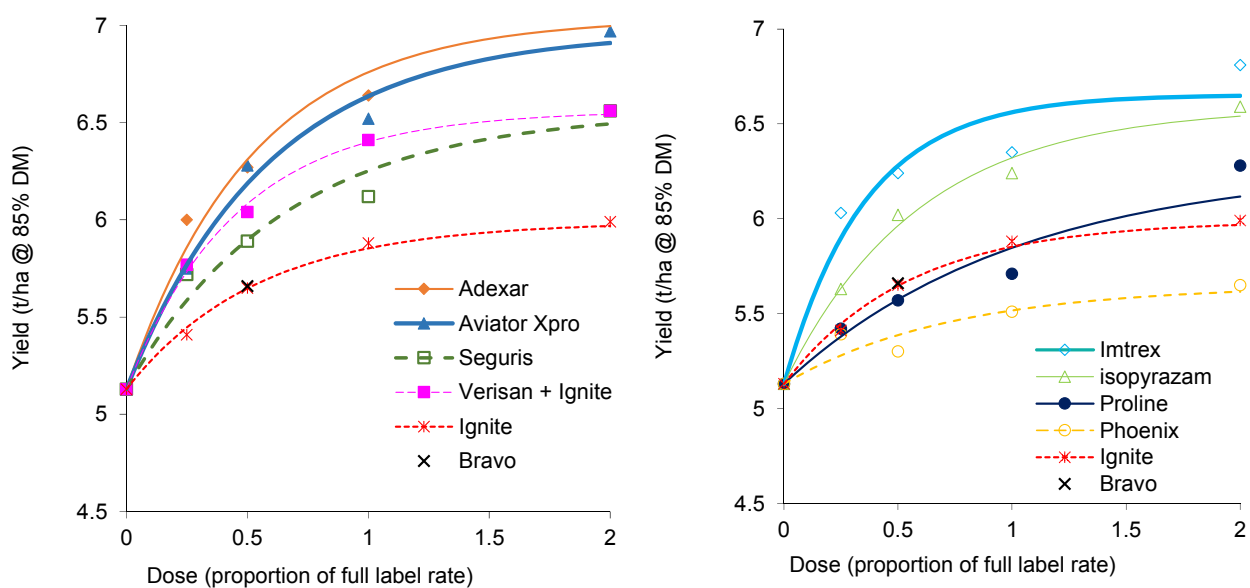


Figure 11. Fungicide dose response curves for yield in Septoria tritici trials in 2012 (overall means across sites 8, 9, 10 and 14)

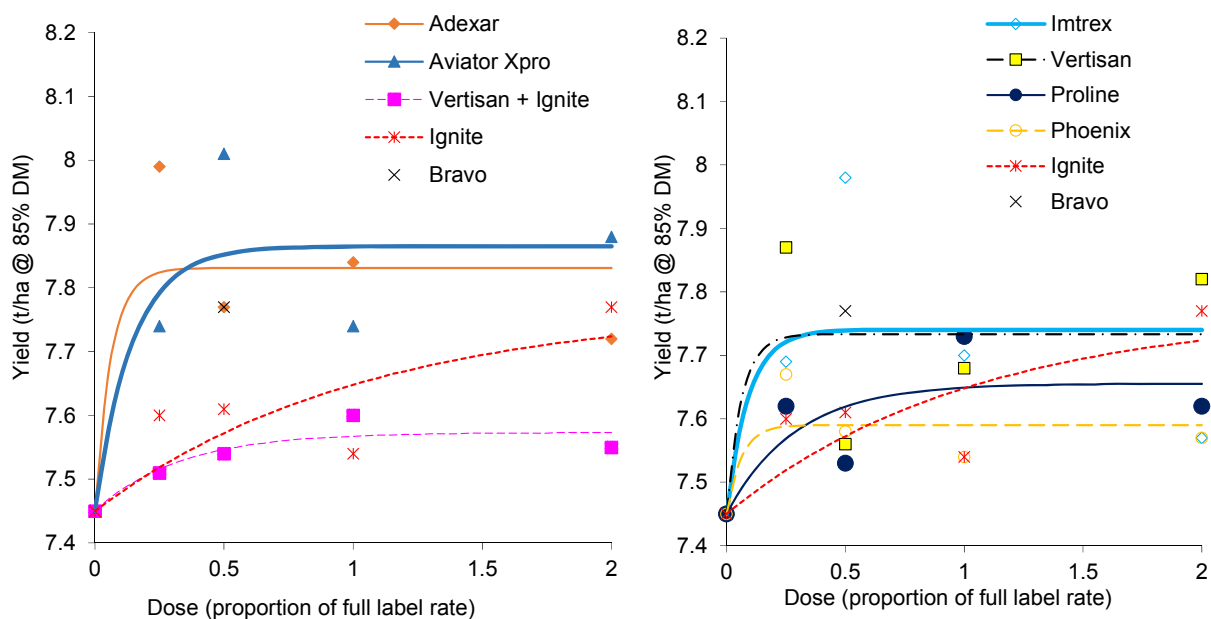


Figure 12. Fungicide dose response curves for yield in Septoria tritici trials in 2013 (overall means across sites 15, 16, 17 and 21)

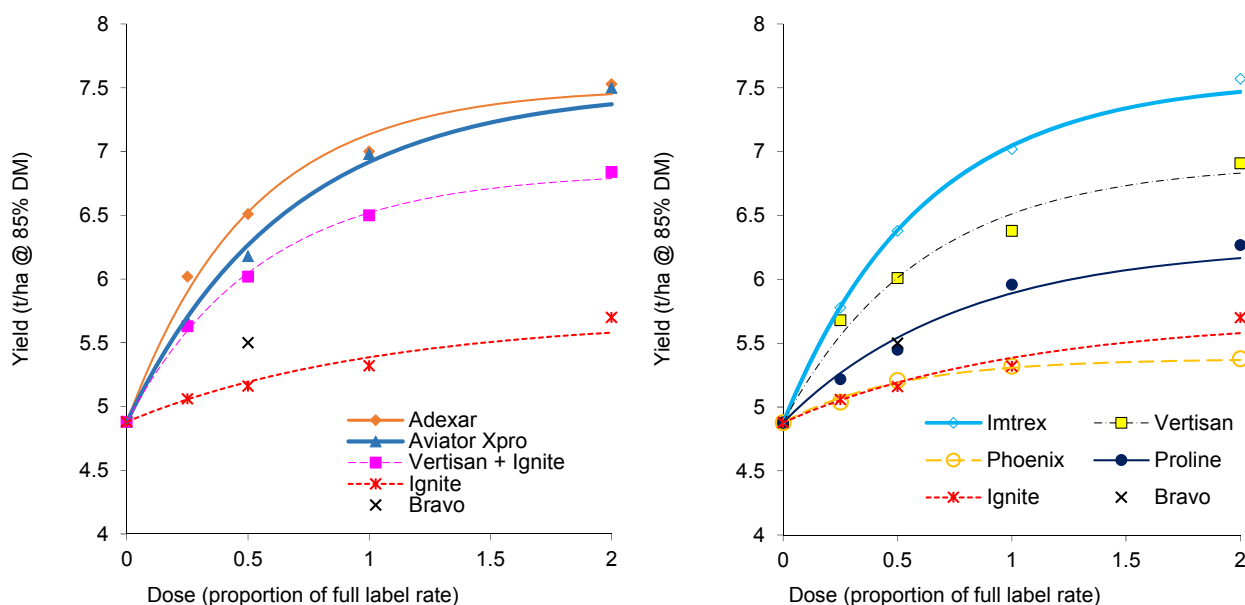


Figure 13. Fungicide dose response curves for yield in Septoria tritici trials in 2014 (overall means across sites 22, 23, 24 and 28)

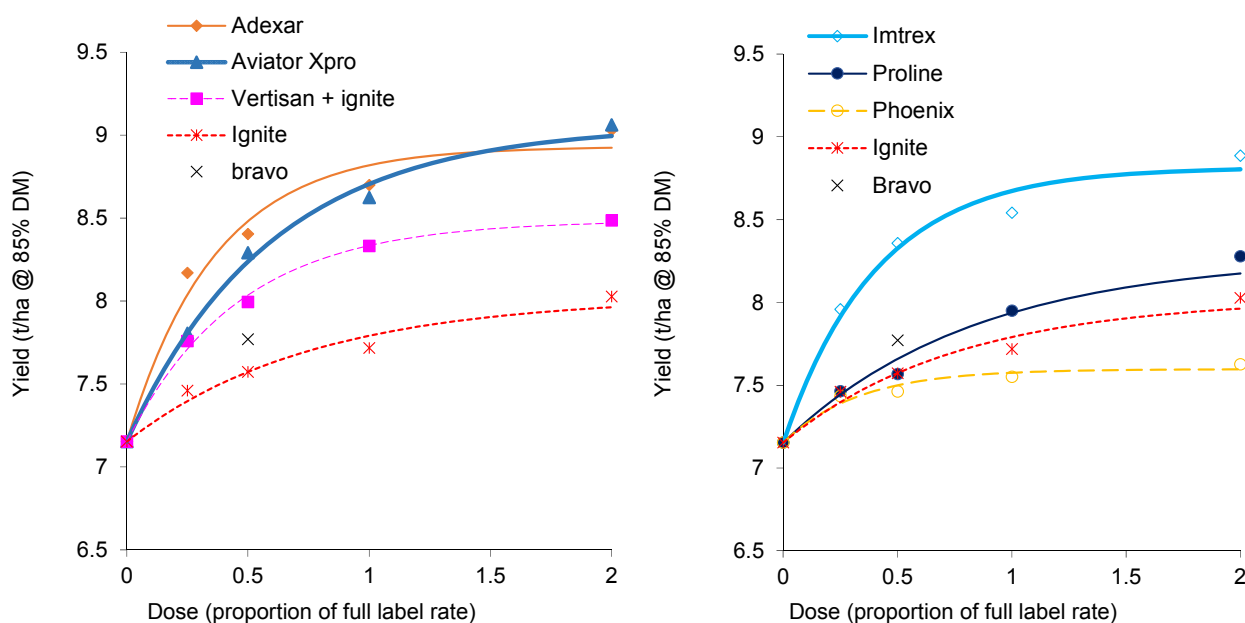


Figure 14. Fungicide dose response curves for yield in Septoria tritici trials; 2011–2014 (overall means across sites 1, 2, 3, 7, 8, 9, 10, 14, 15, 16, 17, 21, 22, 23, 24 and 28)

4.1.3. T1 + T2 trial results

At Sutton Scotney in Hampshire in 2011, the mean level of Septoria on the leaves assessed within the T1 + T2 trial, 3 and 6 weeks after the T2 application was at 20.2% of leaf area in the untreated, and all products applied at half rate at T1 and T2 gave a significant reduction ($P < 0.001$) (Figure 15). There were no significant differences between fungicide treatments, although Septoria tritici levels were particularly low where products containing SDHIs were applied compared with the

straight azoles or Bravo. Brutus appeared to give more effective disease control than the straight azole products. The yield results for this trial broadly reflect the differences in disease control, with an untreated yield of 9.48 tonnes/ha, and all fungicide treatments giving a significant increase, with yields ranging from 10.38 to 11.20 tonnes/ha ($P=0.002$) (Figure 16). Seguris treated plots had a highest yield at 11.20 tonnes/ha, which was significantly higher than Proline, Opus, Ignite or Bravo ($P=0.002$).

At the site in Balgonie, Fife, the mean level of Septoria on the leaves assessed was similar, with 24.7% in the untreated, and all fungicide treatments applied at half rate at T1 and T2 giving a significant reduction ($P<0.001$) (Figure 17). Again, the products containing SDHIs appeared to give more effective control of Septoria tritici than the straight azole products or Bravo. Aviator Xpro, Adexar and Seguris reduced Septoria tritici to significantly lower levels than Opus, whilst Adexar and Seguris also reduced Septoria tritici to significantly lower levels than Proline ($P<0.001$). Yields differences reflected disease control, with an untreated yield of 6.68 tonnes/ha and all fungicides giving a significant increase, with yields ranging from 7.76 to 9.11 tonnes/ha ($P<0.001$) (Figure 18). Aviator, Brutus, Adexar, isopyrazam and Seguris all gave a significantly higher yield than Opus, whilst Seguris, Brutus and Adexar also gave a significantly higher yield than Bravo ($P<0.001$).

At the site in Carlow, Ireland, the level of Septoria on assessed leaves was low with 3.3% Septoria tritici in the untreated plots, and all fungicide treatments giving a significant reduction ($P<0.001$) (Figure 19). Folicur gave significantly less effective control of Septoria tritici than all other fungicide treatments ($P<0.001$), and although not significant, treatments containing SDHIs appeared to give more effective control of Septoria tritici. The untreated yield was 8.89 tonnes/ha, and all treatments gave a significant increase, with yields ranging from 10.58 to 13.17 tonnes/ha ($P<0.001$) (Figure 20). All treatments gave a significantly higher yield than Folicur, whilst Aviator Xpro, Adexar, Brutus and isopyrazam treatments yielded significantly higher than Caramba and Ignite ($P<0.001$).

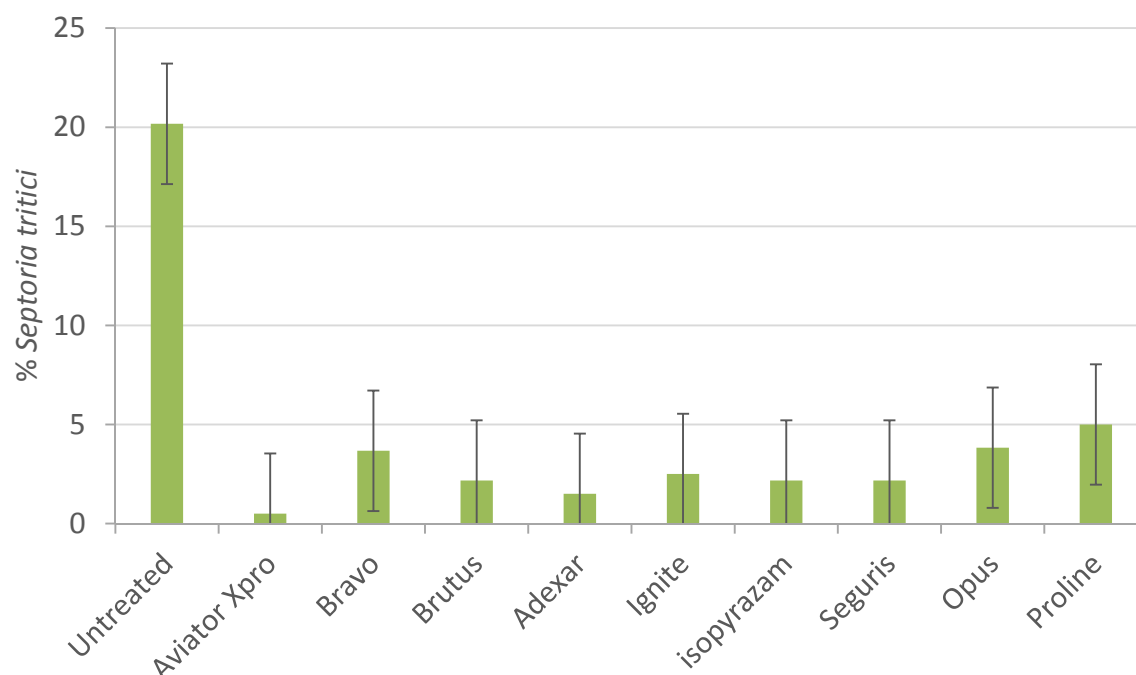


Figure 15. *Septoria tritici* levels as percent leaf area for plots treated with half rate doses of fungicides at T1 and T2 at Sutton Scotney, Hampshire (site 2) in 2011. Error bars in all bar charts in this report represent least significant difference at $P=0.05$

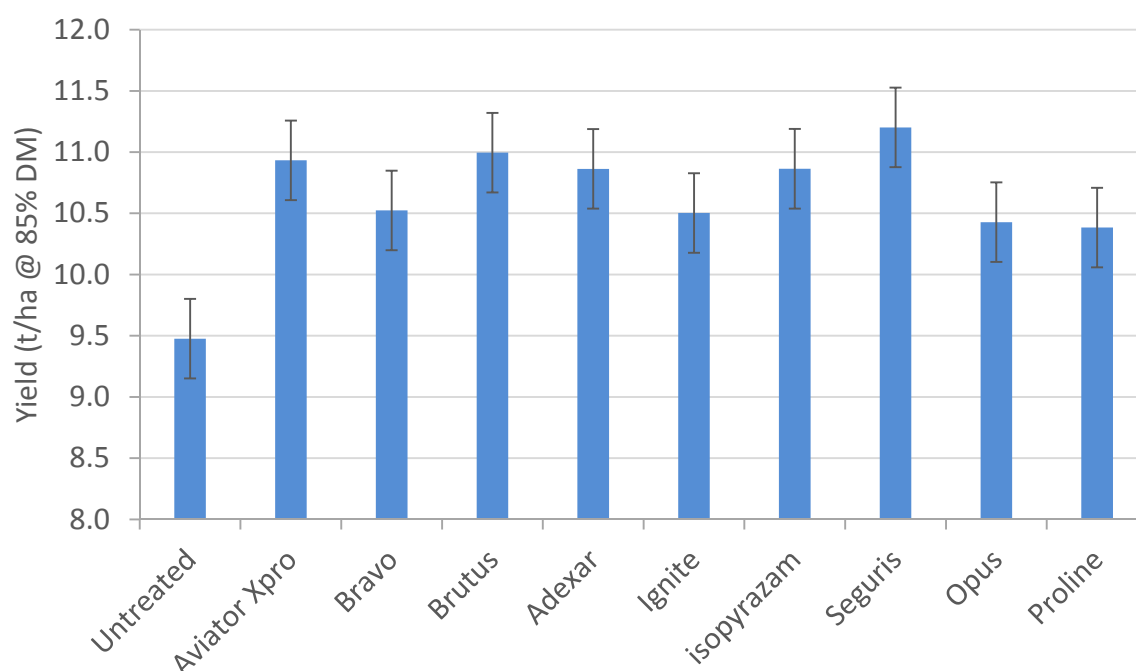


Figure 16. Grain yields for plots treated with half rate doses of fungicides at T1 and T2 at Sutton Scotney, Hampshire (site 2) in 2011

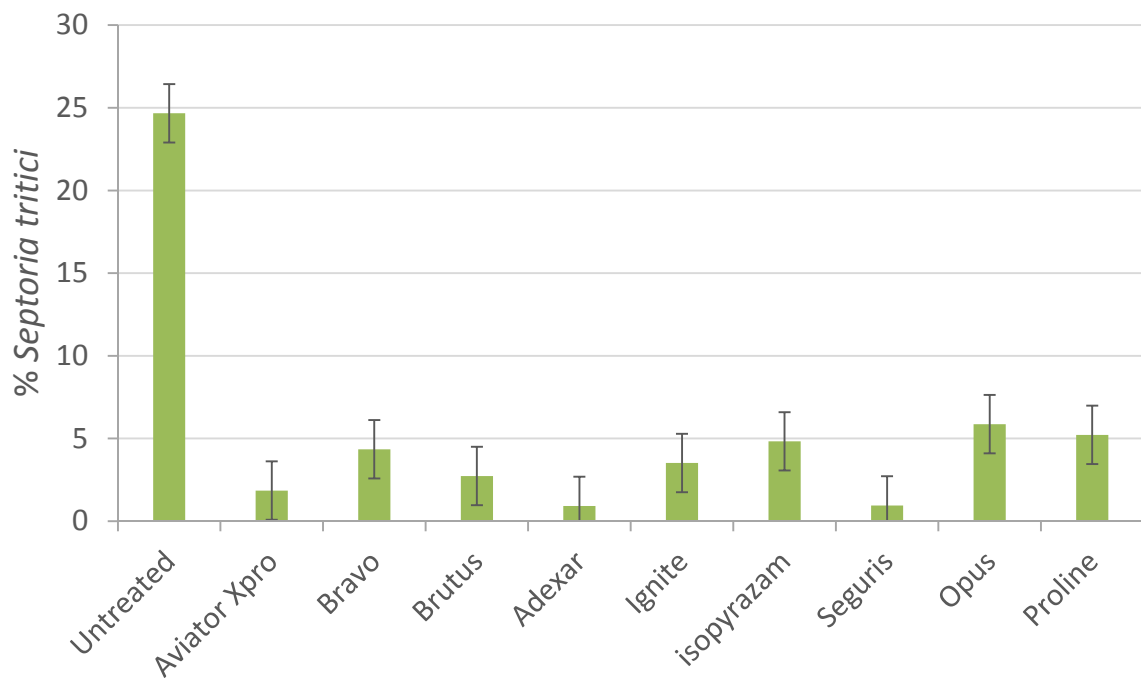


Figure 17. *Septoria tritici* levels as percent leaf area for plots treated with half rate doses of fungicides at T1 and T2 at Balgonie, Fife (site 3) in 2011

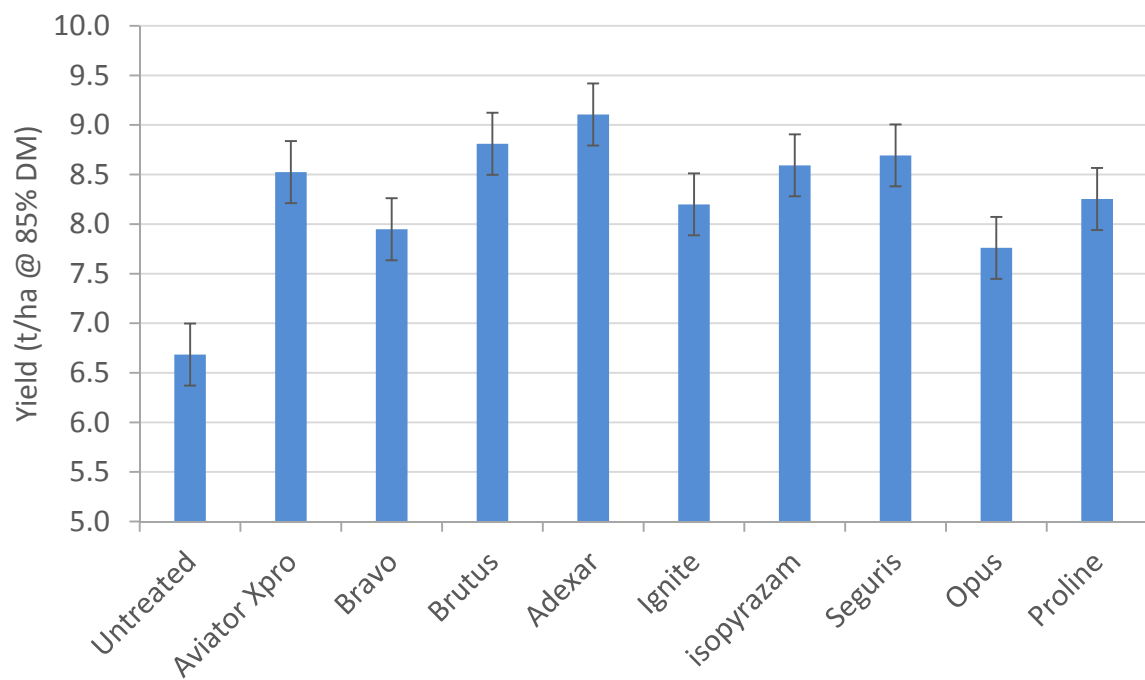


Figure 18. Grain yields for plots treated with half rate doses of fungicides at T1 and T2 at Balgonie, Fife (site 3) in 2011

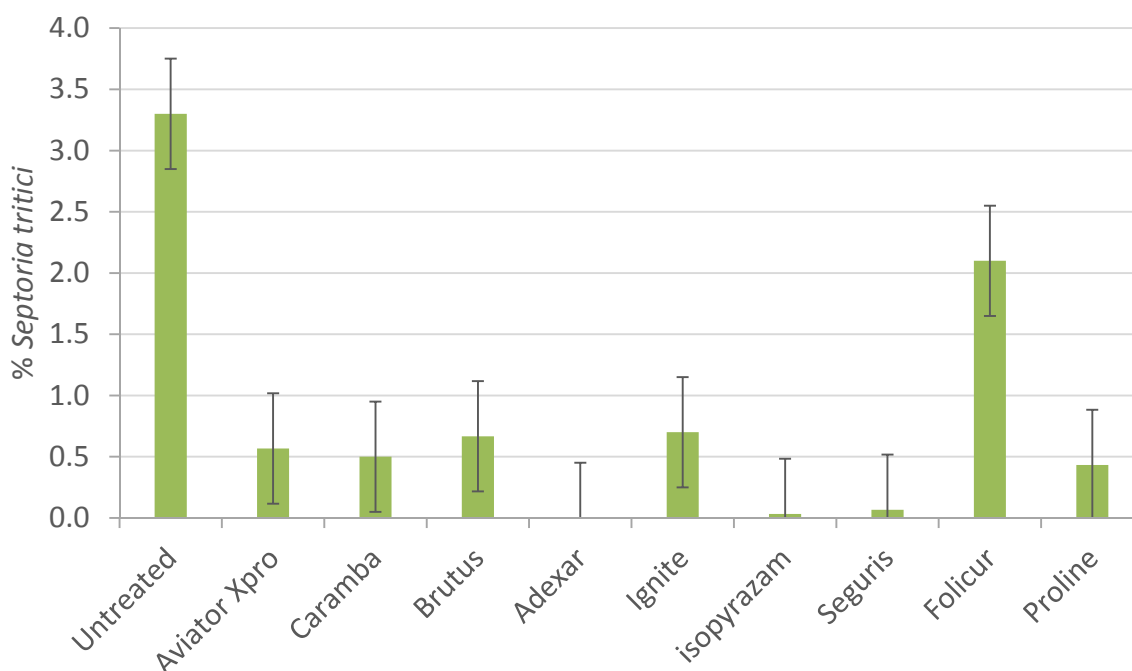


Figure 19. *Septoria tritici* levels as percent leaf area for plots treated with half rate doses of fungicides at T1 and T2 at Carlow, Ireland (site 7) in 2011

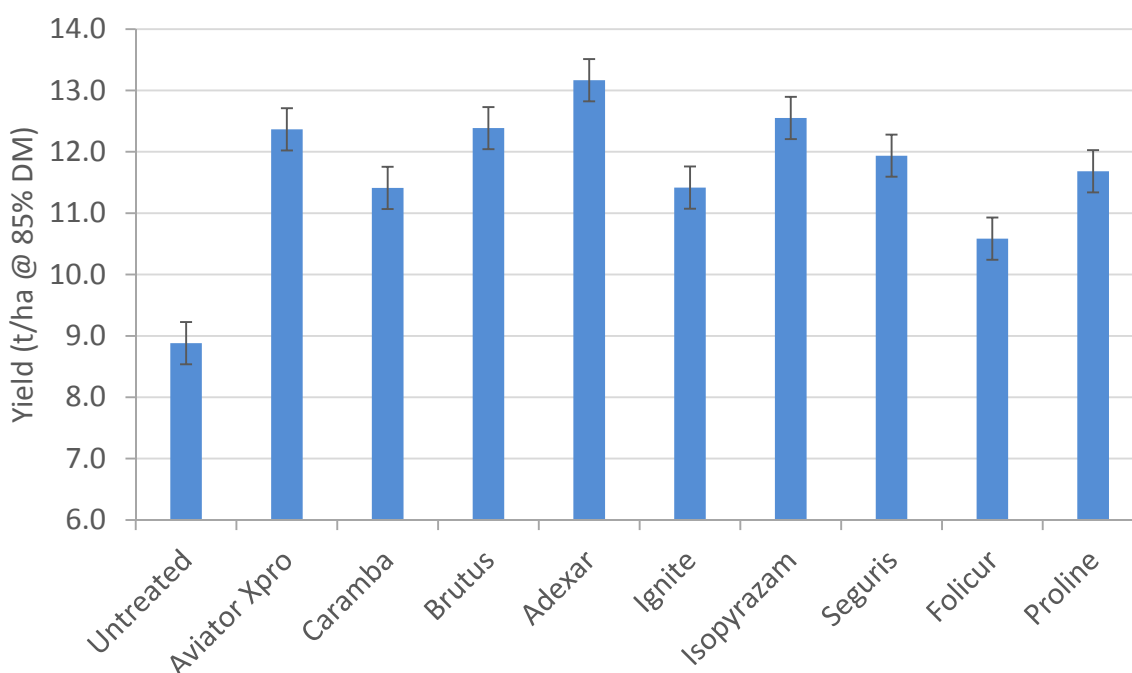


Figure 20. Grain yields for plots treated with half rate doses of fungicides at T1 and T2 at Carlow, Ireland (site 7) in 2011

4.1.4. Timing trial results

In each season, the % control of *Septoria tritici* achieved by half label rates that were applied at each of the 5 timings was evaluated for each leaf layer and, where significant, included within the cross-site and season evaluation as detailed below. The results from different leaf layers and

seasons were combined by aligning the fitted timing response curves along the spray timing axis according to the optimum timings. This enabled cross-season timing response curves to be fitted to the data for each product.

Table 6. Curve fit parameters and standard errors (S.E.) for timing response curves fitted to the 2011-2014 data. Note: Vertisan became available for inclusion in trials one year later than the other products tested and further data are required to obtain a reliable comparison between spray windows.

	Adexar	Aviator	Imtrex	Isopyrazam	Seguris
Sigma	26.38	20.80	24.42	17.12	13.09
S.E.	3.09	2.03	3.41	1.76	1.10
Theta	81.24	79.88	80.42	86.25	86.81
S.E.	4.50	4.79	5.87	6.07	5.83

The width of the spray window is described by the parameter sigma (2xsigma is the estimated spray window, in days, during which the percent control achieved was greater than half that achieved at the optimum timing). Significant differences between products were identified by the analysis. The spray window for the straight SDHI Imtrex was estimated to be wider than isopyrazam, and the spray window for the SDHI-azole mixtures Aviator Xpro and Adexar was estimated to be wider than Seguris. Differences between products in theta (which represents the % control achieved at the optimum timing from the 0.5 label rate) were less clear, but indicated that isopyrazam and Seguris were at least as effective as the other straight SDHI or mixture products, respectively, when applied at the optimum timing.

4.2. Yellow rust experiments

4.2.1. Disease control

In 2011, there were moderate levels of yellow rust, and all treatments gave a very good level of control. Comet (pyraclostrobin) and isopyrazam appeared to give less effective control of yellow rust compared to Proline, Ignite, Brutus, Adexar, Aviator Xpro and Seguris (Figure 21).

In 2012, yellow rust pressure was much higher, and clear differences between treatments became apparent. Ignite provided very effective control of yellow rust, as did all products containing epoxiconazole (Brutus, Adexar, Seguris and Vertisan + Ignite) (Figure 22). Comet and Proline also gave good control of yellow rust, although not as effective as Ignite. The straight SDHIs Imtrex and isopyrazam both gave a useful level of control of yellow rust, although neither were comparable to the most effective azole based products. Isopyrazam was slightly more effective on yellow rust than Imtrex. Of the SDHI-azole combinations, Adexar, Seguris and Vertisan + Ignite, gave more effective control of yellow rust than Aviator Xpro.

In 2013, yellow rust levels were very low and all products controlled yellow rust effectively. As a result, there was no clear separation between products in terms of yellow rust control (Figure 23). In 2014, yellow rust pressure was extremely high, due to mild overwinter temperatures with very few frosts. Ignite, and all products containing epoxiconazole, again gave very effective control of yellow rust. Comet, although not quite as active, did provide a good level of control (Figure 24). The straight SDHI products Imtrex and Vertisan both gave a useful level of yellow rust control, although neither was as effective as Ignite or Comet. Aviator Xpro especially at the 0.25 and 0.5 doses did not give as effective control of yellow rust as the other SDHI-azole mixtures. Phoenix did show a low level of protectant activity against yellow rust, which could be a useful addition in mixtures but this efficacy was less than seen against *Septoria tritici*.

Analysis over the 4 years shows that Ignite gave highly effective control of yellow rust (Figure 25). Comet and Proline, although not quite as effective as Ignite, still gave good control of yellow rust. Imtrex was less effective, but showed the SDHIs may add a useful level of control of yellow rust when used in mixtures. All SDHI-azole mixtures tested gave highly effective control of yellow rust, particularly those containing epoxiconazole.

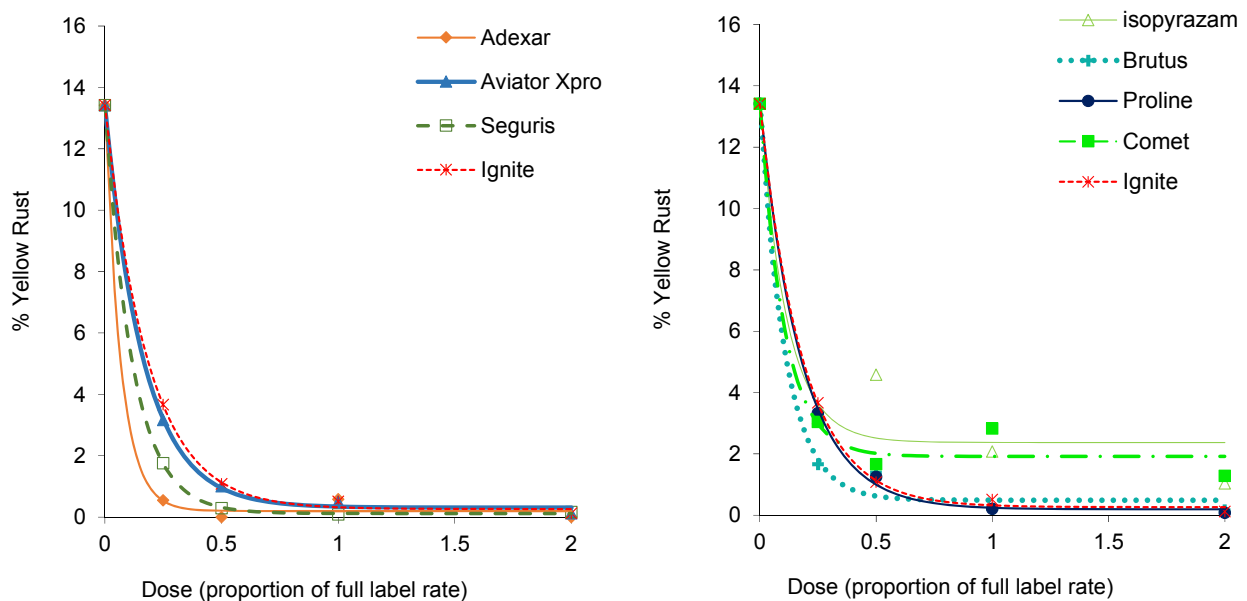


Figure 21. Fungicide dose-response curves for yellow rust control in 2011 (site 4)

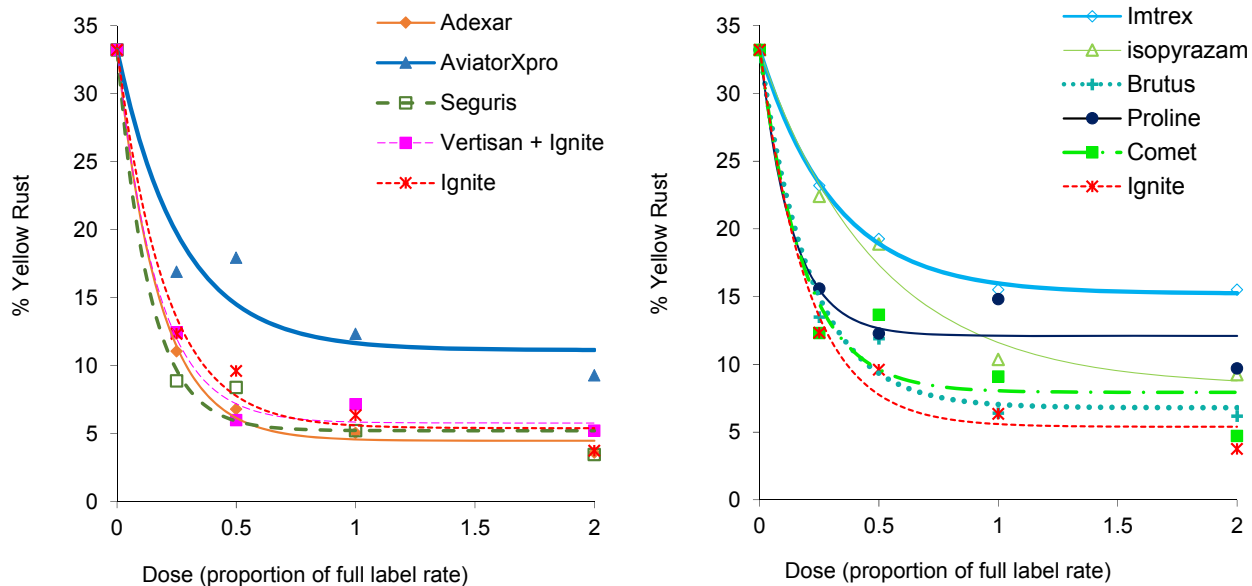


Figure 22. Fungicide dose-response curves for yellow rust control in 2012 (site 11)

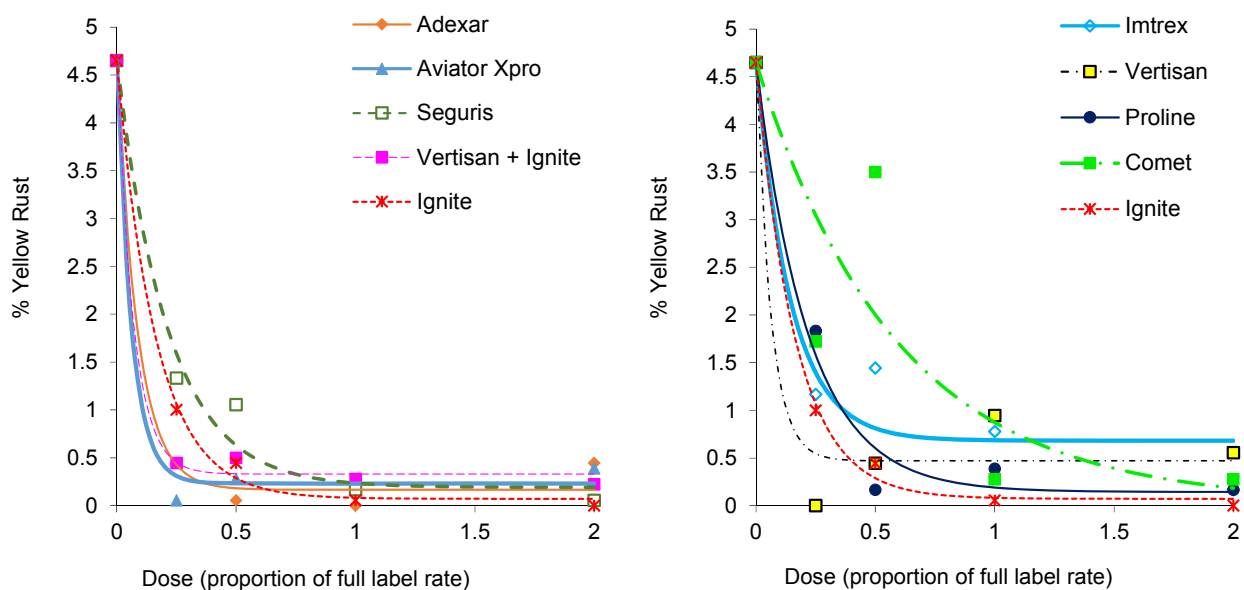


Figure 23. Fungicide dose-response curves for yellow rust control in 2013 (site 18)

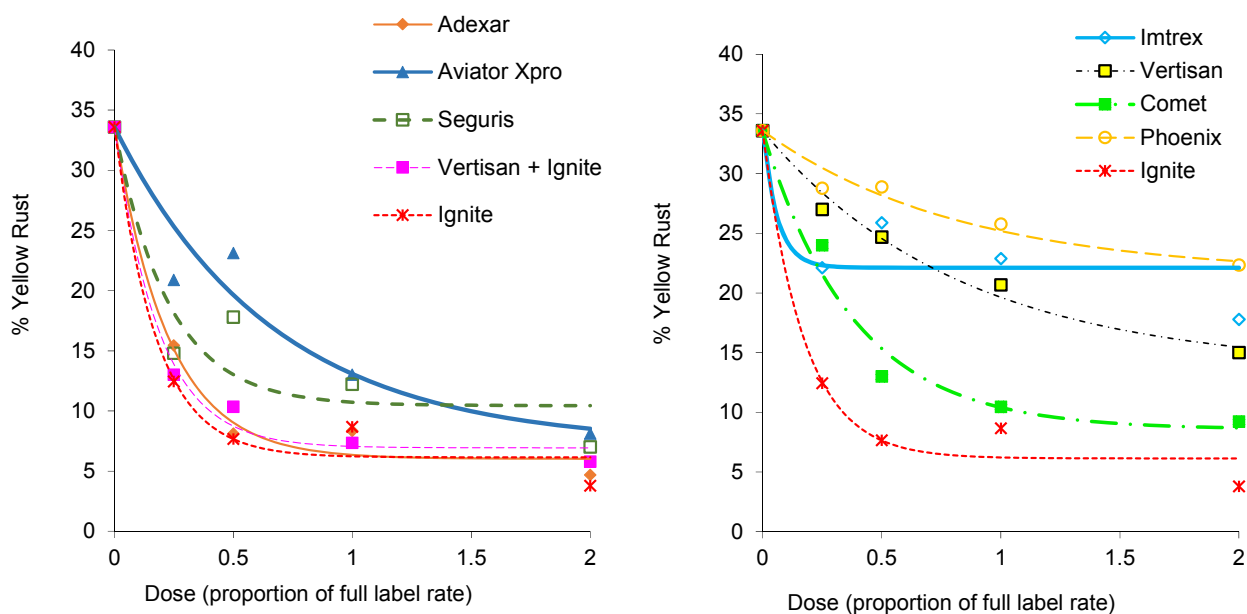


Figure 24. Fungicide dose-response curves for yellow rust control in 2014 (site 25)

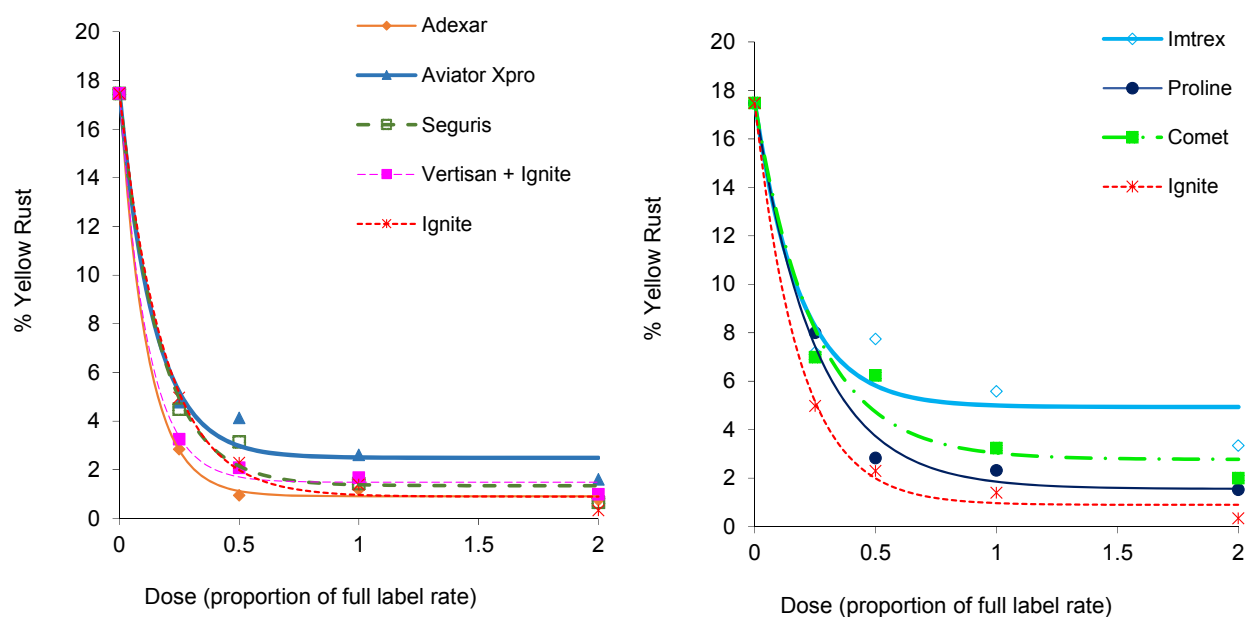


Figure 25. Fungicide dose-response curves for yellow rust control; 2011-2014 (overall means across sites 4, 11, 18 and 25)

4.2.2. Yield

In 2011, yields followed a broadly similar pattern to disease control, and yield responses from applying single full dose applications ranged from 1.27 tonnes/ha to 2.42 tonnes/ha (Figure 26). Applied at full dose, Ignite gave a yield response of 2.05 tonnes/ha. Adexar and Seguris appeared to give a slightly higher yield response than Ignite (2.42 and 2.28 tonnes/ha, respectively). Aviator Xpro was intermediary between Ignite and Adexar / Seguris. Proline and Comet gave a lower yield response when compared to Ignite (1.57 and 1.27 tonnes/ha, compared to 2.05 tonnes/ha).

Despite high levels of yellow rust and some good levels of control in 2012, yield responses to fungicides were relatively low. As with the *Septoria tritici* trials, this was due to dull weather during grain filling. Yield responses from applying single full dose applications ranged from 0.05 tonnes/ha to 0.95 tonnes/ha (Figure 27). A single application of full dose Ignite gave a yield response of 0.60 tonnes/ha, and all products containing epoxiconazole gave a higher yield response compared to Proline or Aviator which had a yield response of 0.05 tonnes/ha and 0.31 tonnes/ha, respectively. Single full dose applications of Adexar, Vertisan + Ignite and isopyrazam gave the highest yield responses (0.94, 0.79 and 0.95 tonnes/ha, respectively).

In 2013, the yield response to fungicides where single full dose treatments were applied ranged from 0.56 to 1.61 tonnes/ha. Ignite gave a yield response of 1.33 tonnes/ha when a single dose was applied at full rate (Figure 28). The straight SDHIs Imtrex and Vertisan also showed good yield responses of 1.11 and 1.00 tonnes/ha.

In 2014, the exceptional yellow rust pressure resulted in a very low untreated yield of 4.97 tonnes/ha (Figure 29). Imtrex and Comet gave a small increase in yield, although this was only small due to the severe disease pressure. In line with disease control, Ignite gave the highest yield response of 1.13 tonnes/ha above the untreated where a single full dose was applied. SDHI-azole combinations gave yield responses ranging from 0.55 tonnes/ha to 0.88 tonnes/ha. The yield response to Aviator Xpro appeared to be lower than for the other SDHI-azole combinations.

The over 4 years analysis showed that yield increases from single full dose applications ranged from 0.55 tonnes/ha to 1.56 tonnes/ha (Figure 30). A single full dose application of Ignite gave a yield increase of 1.28 tonnes/ha. A single full dose application of Imtrex gave a yield response of 1.04 tonnes/ha, whilst Comet and Proline yields appeared to be slightly lower with responses of 0.78 tonnes/ha and 0.55 tonnes/ha, respectively. All SDHI-azole combinations gave large increases in yield, ranging from 1.0 tonnes/ha to 1.56 tonnes/ha. Aviator Xpro generally appeared to give a lower increase in yield than the other SDHI-azole combinations.

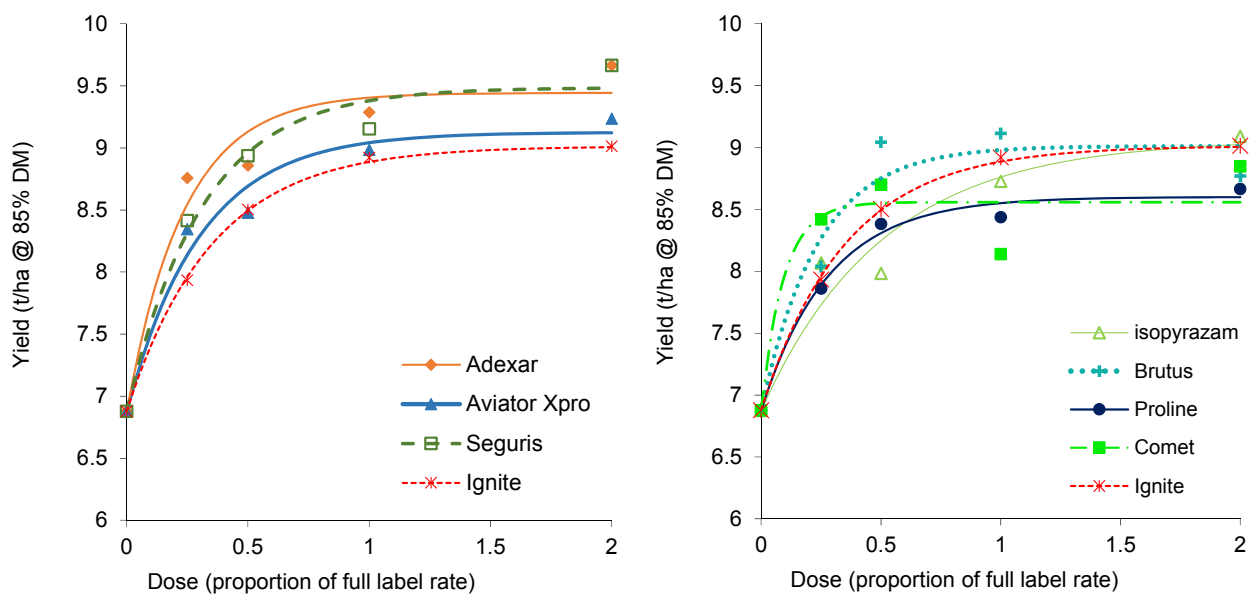


Figure 26. Fungicide dose response curves for yield in yellow rust trials in 2011 (site 4)

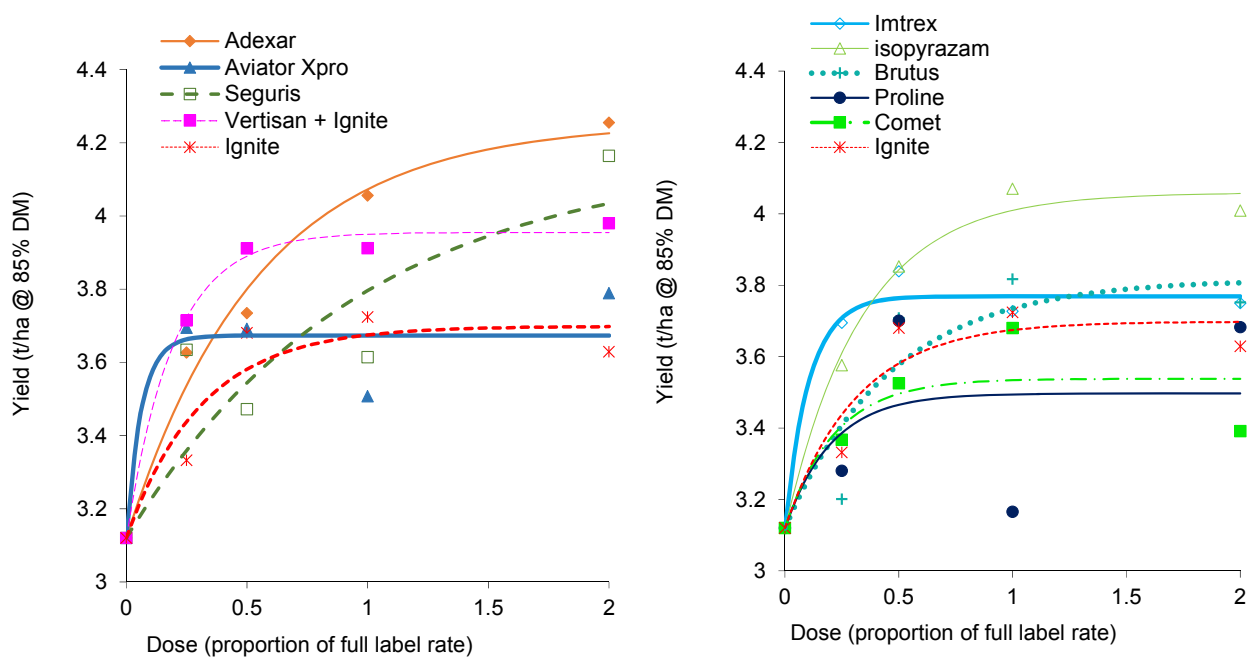


Figure 27. Fungicide dose response curves for yield in yellow rust trials in 2012 (site 11)

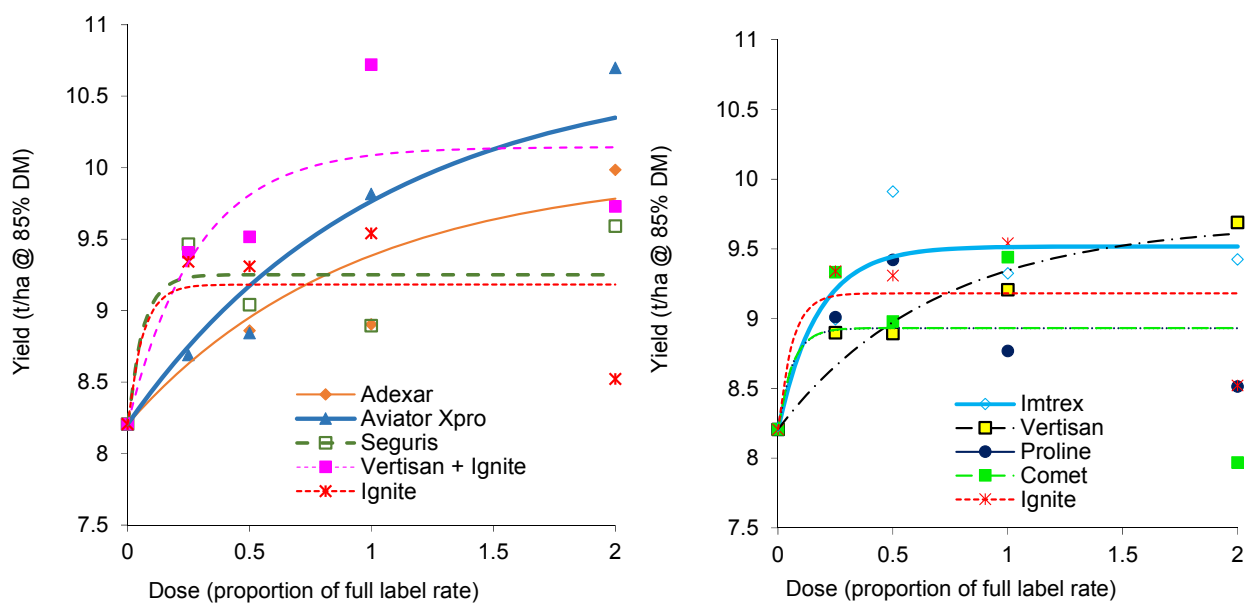


Figure 28. Fungicide dose response curves for yield in yellow rust trials in 2013 (site 18)

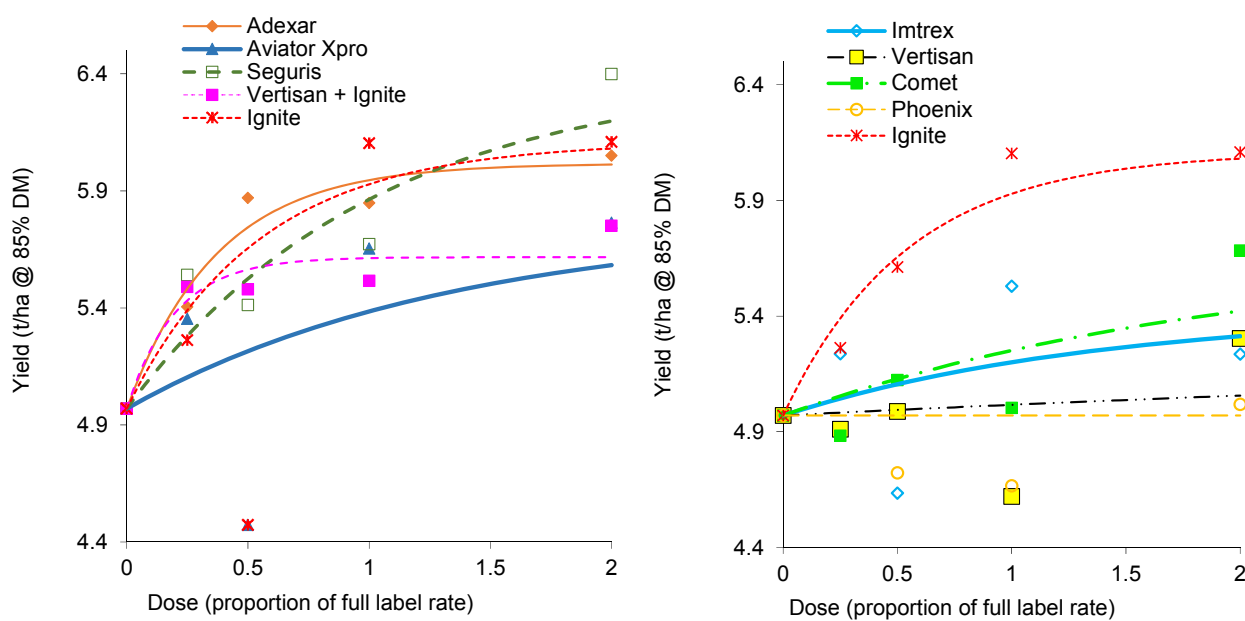


Figure 29. Fungicide dose response curves for yield in yellow rust trials in 2014 (site 25)

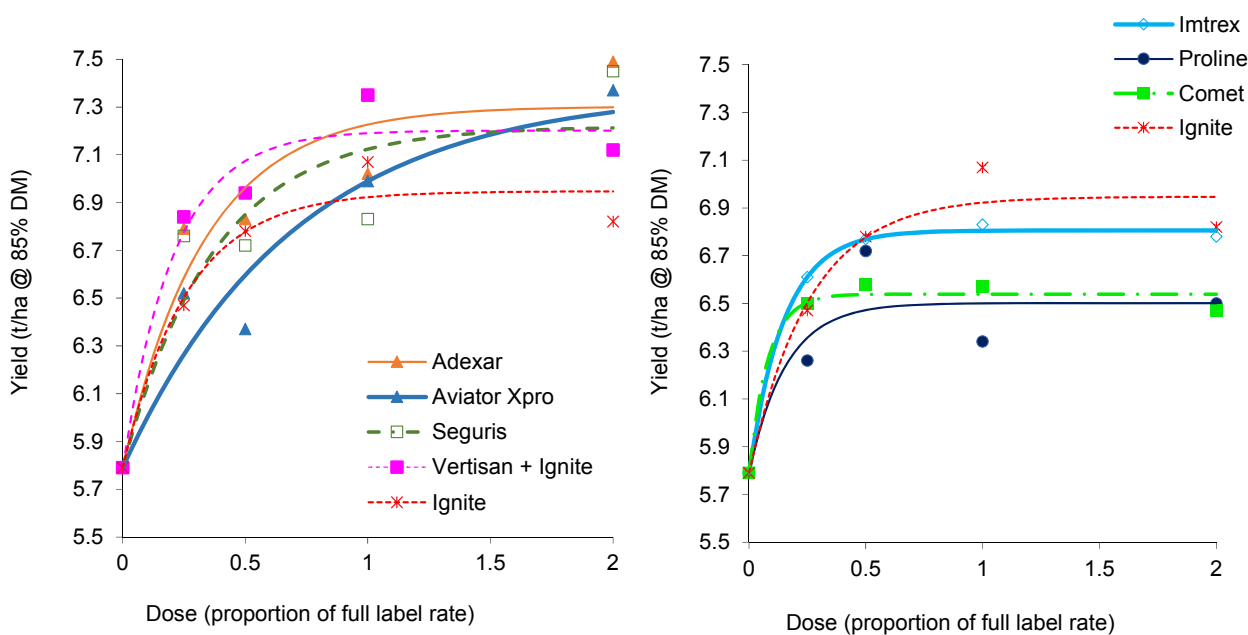


Figure 30. Fungicide dose response curves for yield in yellow rust trials in 2011-14 (overall means across sites 4, 11, 18 and 25)

4.2.3. T1 + T2 trial

In the T1 + T2 trial yellow rust trial, assessments at 3 and 6 weeks post T2 applications indicated 76.7% yellow rust in the untreated on assessed leaves, and all treatments gave a significant reduction with levels ranging from 0 to 21.7% ($P < 0.001$) (Figure 31). Brutus, Comet, Adexar, Seguris, Ignite and isopyrazam all reduced yellow rust to significantly lower levels than Proline or Aviator Xpro ($P < 0.001$). The untreated yield was 6.44 tonnes/ha, and all treatments gave a significant increase, with yields ranging from 8.52 to 9.80 tonnes/ha ($P < 0.001$) (Figure 32). Brutus, Adexar, Seguris, Ignite and isopyrazam gave a significantly higher yield than Proline ($P < 0.001$).

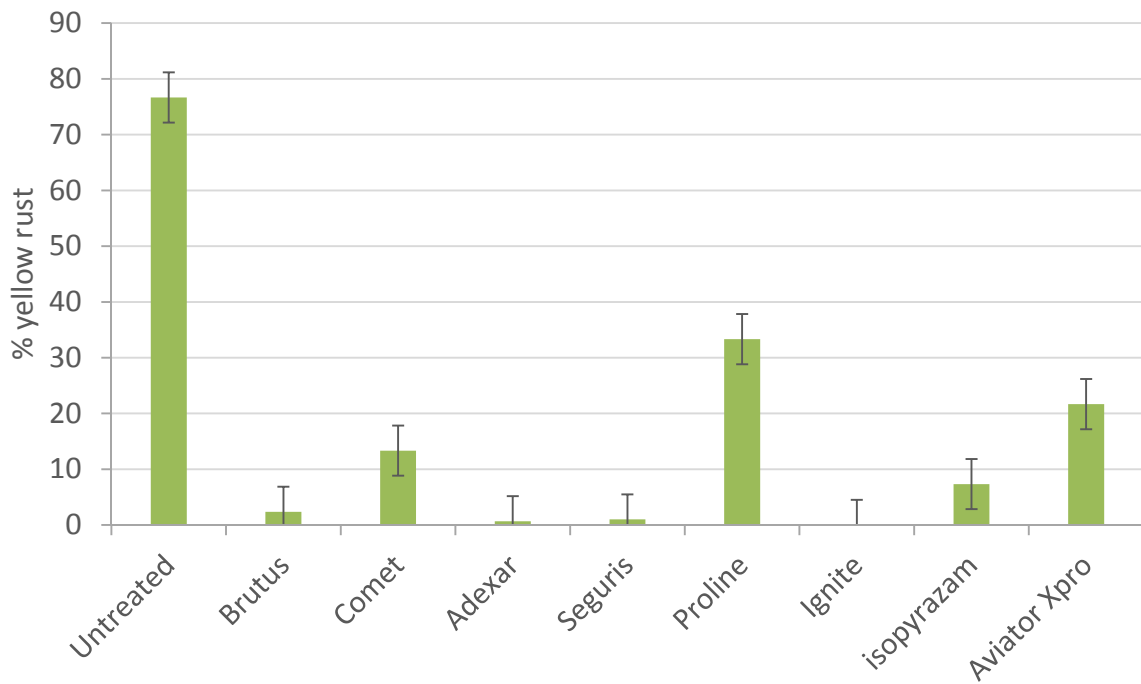


Figure 31. Yellow rust levels as percent leaf area for plots treated with half rate doses of fungicides at T1 and T2 at Terrington, Norfolk (site 4) in 2011

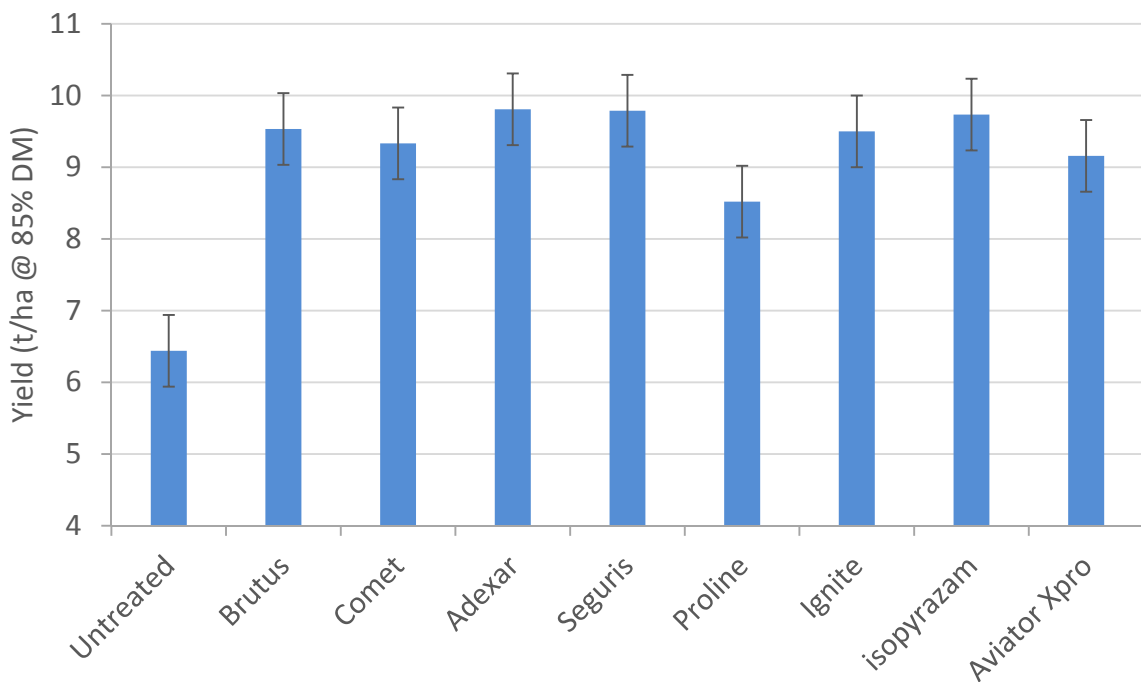


Figure 32. Grain yields for plots treated with half rate doses of fungicides at T1 and T2 at Terrington, Norfolk (site 4) in 2011

4.3. Brown rust experiments

4.3.1. Disease control

Brown rust was present in the trials in 2012 and 2014. In 2012, the straight products Imtrex, isopyrazam and Ignite all gave very effective control of brown rust, reducing levels to below 2% at quarter dose, as did all SDHI-azole mixtures (Figure 33). Proline appeared to give slightly less effective control of brown rust than these treatments. Phoenix only appeared to give a very small reduction in brown rust levels, and the level of control did not increase with dose. In 2014, the fungicide treatments were applied after brown rust had established in the crop, and so it was a more eradicant situation. This resulted in higher brown rust levels and some greater differences between products. Comet gave very effective control of brown rust, with a quarter dose reducing levels to 2.4%, and half dose reducing levels to below 1% (Figure 34). Ignite and the two straight SDHIs Imtrex and Vertisan also showed a good level of activity against brown rust, although were not as effective as Comet. At full dose, these treatments reduced brown rust levels to between 2.7% and 8.3%. All SDHI-azole mixtures gave good control of brown rust, although were not as effective as Comet. When compared with other products in this more eradicant situation, Aviator Xpro appeared to be less effective at the control of brown rust compared to the other SDHI-azole mixtures tested.

Analysis over both years showed that Comet gave highly effective control of brown rust (Figure 35). Imtrex and Ignite, although not as effective as Comet, both gave good control of brown rust. The SDHI-azole combinations Adexar, Aviator Xpro, Seguris and Vertisan + Ignite all gave good control of brown rust.

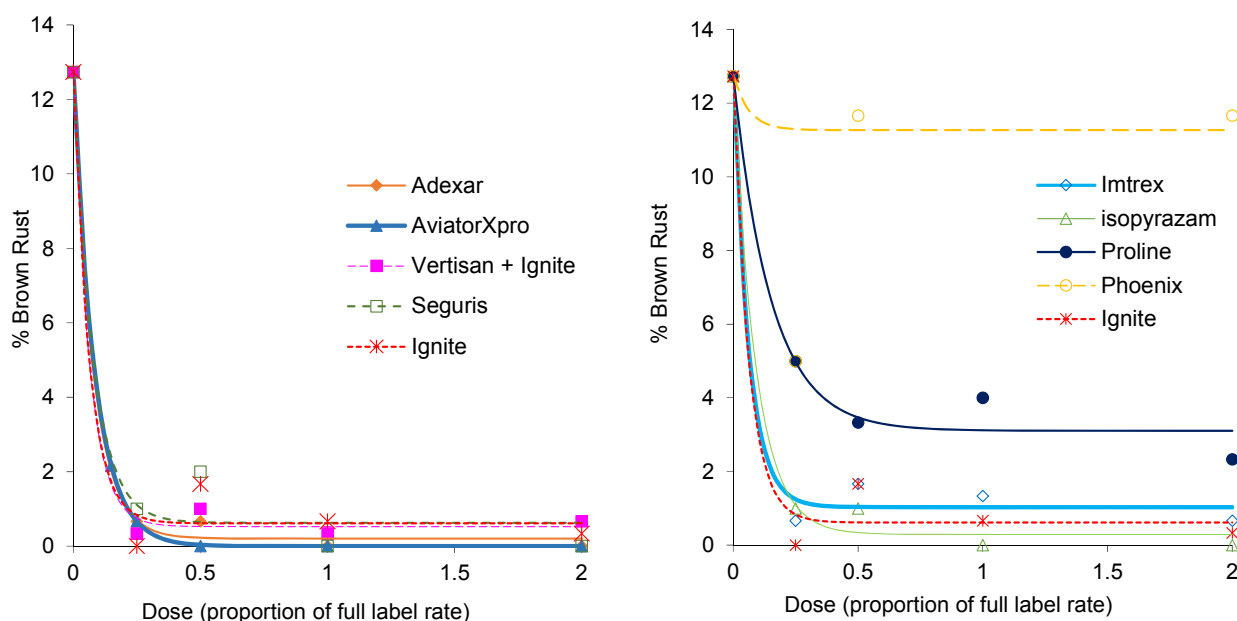


Figure 33. Fungicide dose-response curves for brown rust control in 2012 (site 12)

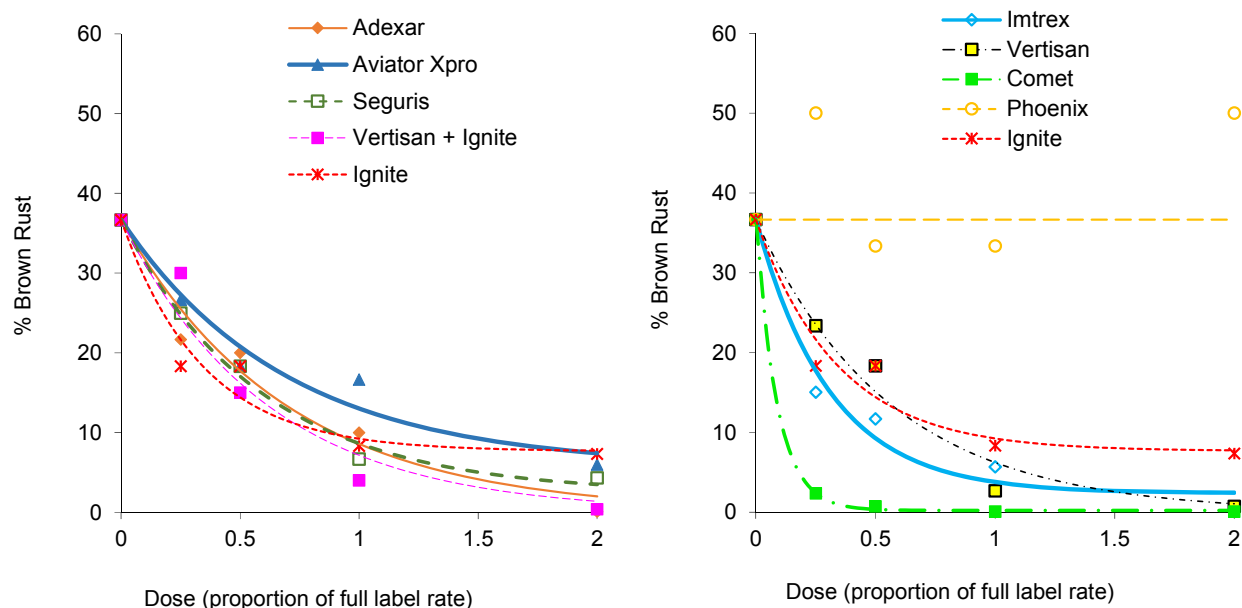


Figure 34. Fungicide dose-response curves for brown rust control in 2014 (site 26)

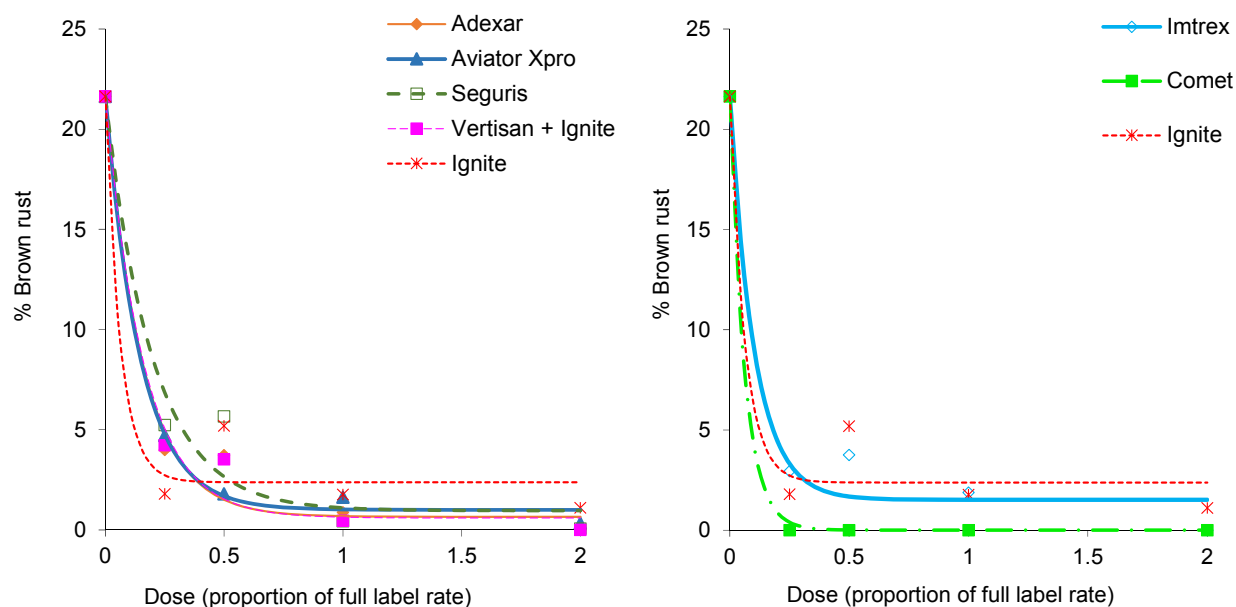


Figure 35. Fungicide dose response curves for brown rust trials in 2012 and 2014 (overall means across sites 12 and 26)

4.3.2. Yield

Yield data from 2012 showed yield responses from single full dose applications ranging from 0.11 to 1.02 tonnes/ha (Figure 36). A single full dose application of Ignite gave a yield increase of 0.54 tonnes/ha. SDHI-azole combinations generally gave a greater yield response with values ranging from 0.82 to 1.02 tonnes/ha where full single dose treatments were applied.

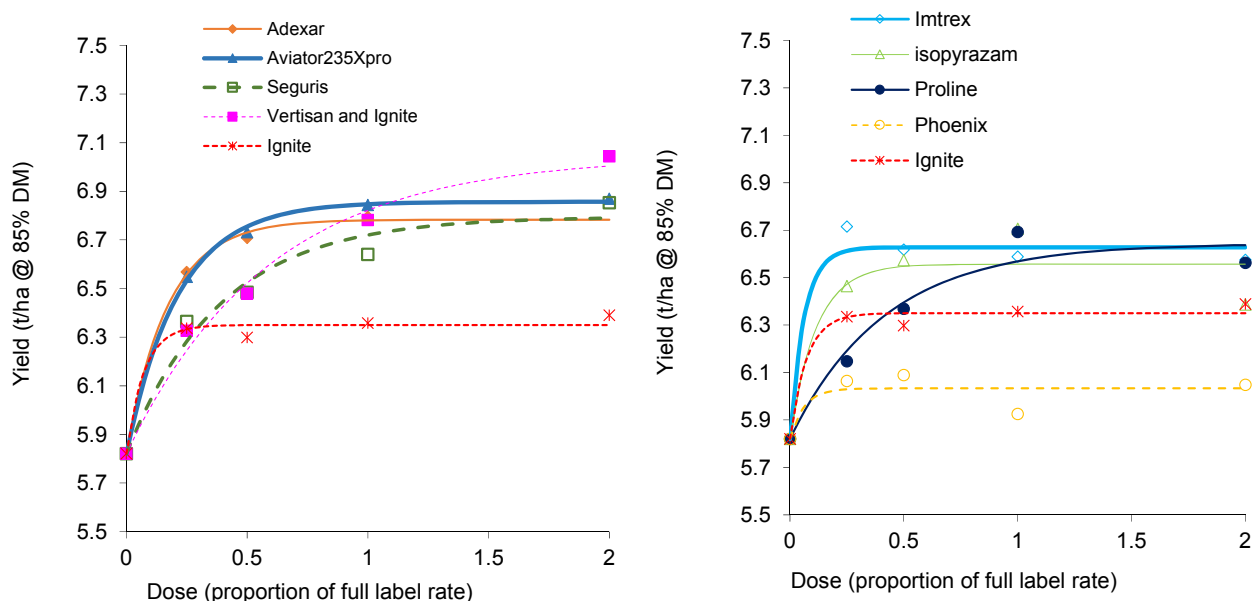


Figure 36. Fungicide dose response curves for yield in brown rust trials in 2012 (site 12)

4.4. Mildew experiments

Between 2011 and 2014 the mildew trials did not have sufficient mildew to allow reliable assessments. This was despite the susceptible variety Claire being sown. The generally low levels of mildew over recent years continues the general decline in the importance of this disease over recent decades, hence mildew will be dropped as a primary target disease in future Fungicide Performance work. The trials did achieve useful levels of Septoria in 2012 and 2014, and this was included within the Septoria analyses for these seasons.

5. Conclusions

All experiments used varieties that were susceptible to the target disease and were located in areas where natural pressure from that disease was high. As a result, responses to fungicides in terms of disease control and yield are likely to have been higher than would have been observed on less susceptible varieties, or on lower pressure sites in these seasons. A single spray application of each product was used as a strong test of protectant or eradicant activity, in order to distinguish differences in product performance more clearly. When interpreting the data, note that this can cause differences in yields between products as a result of small differences in activity, which may not normally be apparent when products are used as part of a commercial fungicide programme.

5.1. Septoria tritici

- Bravo continued to provide very effective protectant activity against *Septoria tritici*. Phoenix also gave a useful level of protectant activity, although when compared at equivalent

proportions of label rate, it was generally less effective. Due to their multi-site mode of action, the risk of resistance development against these products is low, and so they have an important role in providing an alternative mode of action in sequences and mixtures with higher resistance risk groups such as the SDHIs and azoles.

- Opus/Ignite and Proline performed similarly in trials, both providing protectant and eradicant activity against *Septoria tritici*. Whilst they still offer a good level of protectant activity at higher doses, both protectant and eradicant activity has declined due to reduced sensitivity. This decline has been particularly marked in eradicant situations. Differences in protectant activity between Ignite and Proline in 2014 are not thought to represent a change in the relative performance of the two actives.
- The straight SDHI products Imtrex and Vertisan provided a higher level of protectant and eradicant activity than the azoles. Isopyrazam gave a higher level of protectant activity than the azoles (although isopyrazam was not launched as a straight product on wheat, this information is useful in determining the activity of mixtures that contain this active).
- The SDHI-azole mixtures Aviator Xpro, Adexar and Vertisan + Ignite all provided a higher level of protectant and eradicant activity than either the SDHI or azole components alone. Seguris gave a similar level of protectant activity to Aviator Xpro, Adexar or Vertisan + Ignite, but was less effective in eradicant situations.
- When comparing fungicides, differences in yield response were generally in line with differences in disease control. The yield from Vertisan or Vertisan + Ignite was slightly lower than achieved with other treatments giving the same level of disease control when assessed. This may indicate small differences in the persistency of the protection given by the fungicides, impacting for example on retention of green leaf area

The spray timing trial indicated that some products differ in the effective width of their spray window, although efficacy of SDHI-based products was similar when they were applied at optimum timings. In reality, most applications in wheat, although timed to coincide with the emergence of a certain leaf (e.g T1 at leaf 3 emerged, or T2 at leaf 1 emerged) are aiming to control disease on more than one leaf layer, so the differences detected in this work are most likely to be relevant in situations where, for example, the T2 treatment is delayed by weather.

T1 + T2 trials in 2011, indicated that, in a protectant season, azoles applied in sequence can provide adequate levels of disease control, however SDHI azole mixtures were more effective, and generally yielded more. Also in this predominantly protectant season 0.5 dose applications of Seguris appeared to be equally as effective as other SDHI azoles applied at half label rate, at 2 of the 3 sites.

5.2. Yellow rust

- Products containing epoxiconazole (Ignite, Brutus, Seguris and Adexar) provided excellent control of yellow rust, even at low doses.
- Proline and Comet gave effective control of yellow rust, but were not as effective as epoxiconazole based products.
- The straight SDHIs Imtrex and Vertisan gave a useful level of activity against yellow rust, which could add to the level of control when used in mixtures. Isopyrazam gave more effective control of yellow rust than Imtrex.
- The SDHI-azole treatments Adexar, Seguris and Vertisan + Ignite all gave effective control of yellow rust. Aviator Xpro gave slightly less effective control of yellow rust than the SDHI-azole products containing epoxiconazole.
- Phoenix gave a low level of protectant activity against yellow rust, which could add some useful activity when used in mixtures. However, this disease does not appear on the product label.

T1 + T2 trials in 2011 supported the information from the dose response trials.

5.3. Brown rust

- The strobilurin Comet gave highly effective control of brown rust.
- The straight SDHIs Imtrex, Vertisan and Isopyrazam, showed good control of brown rust, comparing more favourably with Ignite on brown rust than on yellow rust.
- Ignite showed good activity against brown rust but was not as effective as Comet. Proline did not control brown rust as effectively as Ignite.
- The SDHI-azole combinations Adexar, Aviator Xpro, Vertisan + Ignite and Seguris all gave very effective control of brown rust. In the more protectant situation in 2012, Aviator Xpro appeared to have similar efficacy to other products, although in 2014 it did not appear to give quite as effective control of brown rust as the SDHI-azole combinations containing epoxiconazole.
- Phoenix did not show any clear activity against brown rust.

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