# Cropping Strategies

## A summary of recent research findings

Cereal Disease Management PART 1 (Revised 2024)

Disease control in wheat and barley

Issue 11 – Spring 2024

# Contents

# Introduction

Since the publication of the 2022 Cereal Disease Management Strategy, the resilience of New Zealand arable growers has been tested by volatile markets, increasing production costs and extreme weather events. The record high grain prices driven by the war in Ukraine in the 2022/23 season have fallen by around $200/t, and with the cost of production continuing to rise, every on-farm decision requires a high level of scrutiny.

In times like these, it can be tempting to spend big and apply more to squeeze every kilogram of production possible. When grain prices are at record highs, it is easy to justify the cost of an extra fungicide as cheap insurance. But the programme that achieved 12 t/ha at $650/t, still achieves 12 t/ha at $450/t. Further, approaches that may have worked in the past, are increasingly under pressure due to the development of resistance and increased consumer demand for food that has been produced in an environmentally and socially sustainable manner.

Since 2019, FAR's cereal disease research has been aligned with a joint government and industry funded Sustainable Food and Fibre Futures (SFFF) programme called 'A Lighter Touch'. This seven-year cross-sectoral programme, is designed to deliver robust and effective integrated disease management programmes that will support both the profitability of farm businesses and a reduction in synthetic inputs. The goal is to ensure growers retain their social license-to-operate, reduce their reliance on chemistries under regulatory threat and minimise the emergence of pesticide resistance. Essentially, we want to build resilient programmes that are productive, profitable and enable us to keep using the tools we need, when we need them.

This Cereal Disease Management Strategy builds on previous editions by summarising the results of FAR research conducted between 2022 and 2024. It provides an overview of the most important diseases currently affecting wheat and barley in New Zealand, and outlines a range of cereal disease management strategies and approaches derived from numerous FAR research trials. Further, in-depth information on these trials and their results can be found in Part 2 of this strategy, which is available on the FAR website (Cereal Disease Management 2024, Part 2).

Jo Drummond
Senior Researcher – Cereals

***Note: It is important that FAR Strategy documents produced prior to the emergence of resistance are not used as reference for crops grown now. Earlier FAR Strategy documents do not consider current product availability and the need for new approaches to chemical stewardship.***

# What's changed since 2022?

## Wheat

### Key diseases

- In commercial crops and FAR trials, Septoria tritici blotch (STB), caused by the pathogen *Zymoseptoria tritici,* remained the major disease limiting production.
- Leaf rust (*Puccinia tritici*) has been problematic for some cultivars in recent seasons.
- Stripe rust and powdery mildew were still present in some areas, as were Fusarium head blight (FHB) and common eyespot (*Oculimacula yallundae* (W-type) and *O. acuformia* (R-type)
- Yellow Dwarf Virus (YDV) was a seasonal issue depending on prevailing weather and location.

### An integrated pest management (IPM) strategy for wheat

- FAR's IPM strategy for wheat is built on effective use of plant genetics, integrating new crop protection technologies and rationalising fungicide programmes.

### Effective use of plant genetics

- Cultivar selection is the most powerful decision you can make to sustainably manage disease in your crop.
- Disease resistant cultivars provide protection from sub-optimal application timings and allow for reduced pesticide use under various seasonal disease pressures.
- Minimising the number of applications in a season is crucial for pesticide stewardship, helping to prevent the development of pesticide resistance and extend the effectiveness of the chemicals used.
- Pathogen populations can adapt to both cultivars and chemistry.
- In the past 25 years, disease resistance in New Zealand feed wheat has improved, while it has decreased in milling varieties.
- Cultivar mixtures can lower disease severity and fungicide costs while safeguarding against seasonal income loss compared to using a single cultivar. This approach alleviates disease pressure on your cereal genetics and helps maintain your cash flow.

### Integrating new plant protection technologies: Biologicals

- Biopesticides cannot directly replace synthetic chemicals, and there are various logistical factors to consider to ensure their effectiveness.
- But, biopesticides can provide a viable alternative to synthetic pesticides at some timings.
- FAR trials conducted in 2022-23 and 2023-24 found that disease management programmes incorporating both biopesticides and conventional products-maintained disease control and yield without compromise.
- Trial results showed that biopesticides could be used at T3 (Growth stage (GS) 59) and sometimes at T1 and T3 (GS 32 and 59) to reduce the number of fungicides in a season.
- A conventional seed treatment and T2 (GS 39) was still required.
- Incorporating biopesticides into a cereal disease management programme can help reduce the number of fungicide applications in a season and extend the availability of at-risk active ingredients.

### Rationalising fungicide programmes

- Fungicide programmes should aim to strike a balance between disease control, yield, economic returns, and resistance management.
- A well-balanced wheat fungicide programme will consider the number of applications, combine different modes of action in spray mixtures, utilize appropriate dosage rates, and vary products within a mode of action group at different application timings throughout the season and across seasons.
- FAR trials demonstrated that while three-spray, one SDHI programmes often achieved the best balance, the majority of disease control, yield and financial returns were associated with GS 32 (T1) and GS 39 (T2) timings, suggesting GS 59-65 (T3) applications are a lower priority and could be considered based on seasonal disease pressure.

- Additional disease control, yield and economic returns from very early (GS 30-31 – T0) and very late (GS 69-71 – T4) applications were negligible.
- Prioritising application timings can enhance fungicide stewardship strategies, helping to extend the active life of at-risk chemicals by ensuring the appropriate number of applications in a given season.
- Additional resistance management strategies involve using balanced fungicide mixtures that incorporate multiple modes of action, as well as alternating active ingredients within the same mode of action group, both within and across seasons.

## Fungicide resistance

- *Zymoseptoria tritici* (*Zt*) isolates collected from New Zealand wheat crops continue to show reductions in sensitivity to triazole (Group 3) fungicides.
- 'Stacking' triazoles with different cross-resistance pathways can provide increased efficacy and slow the rate of sensitivity shifts.
- Solo-triazole active ingredients should be applied with a mixing partner to improve efficacy and ensure their long-term effectiveness.
- New Zealand *Zt* isolates continue to show less sensitivity to SDHI (Group 7) fungicides in the laboratory, although they still have field efficacy.
- Cross-resistance between SDHIs has been confirmed in New Zealand
- Resistance in both triazoles and SDHIs is driven by the number of applications.

# Barley

## Understanding barley diseases

- In FAR trials, Ramularia leaf spot (RLS) caused by the pathogen *Ramularia collo-cygni* (*Rcc*), scald (*Rynchosporium commune*) and net blotch (*Pyrenophtora teres*) were the major diseases on autumn barley.
- RLS was the main disease in spring barley.
- Fungicide mode-of-action groups have different activity on different barley diseases.
- Triazole (Group 3), multi-site (Group M4), SDHI (Group 7) and strobilurin (Group 11) fungicides all have a role to play in a barley disease management programme.
- The timing of RLS symptom onset is important for predicting yield loss and in making fungicide decisions.
- Applying the right fungicide mode-of-action mixture at the right time could delay the onset of RLS in autumn barley by around two weeks and by two to three weeks in spring barley.
- These delays corresponded to a >90% reduction in RLS severity and yield increases of up to 18%.
- While there are no resistance ratings for RLS in New Zealand barley cultivars, cultivar selection remains important for control of other diseases such as leaf rust, scald and net blotch.

## Appropriate barley fungicide programmes

- Mixing mode-of-action groups improves efficacy and provides broad-spectrum control of multiple barley diseases.
- Three-way mixtures based on a triazole (Group 3) + multi-site (Group M4) with either a strobilurin (Group 11) or SDHI (Group 7) at T1 followed by a triazole + multi-site + SDHI at T2 provided the greatest balance between disease control, yield and economic returns.
- These programmes also supported resistance management by only using a strobilurin or SDHI once in a season.
- The timing of application was just as important as the right fungicide mixture in both autumn and spring sown barley.
- With the appropriate mixture, a T1 application could be postponed until GS 32 without affecting disease control, yield, or economic returns, providing flexibility if GS 31 is missed due to unfavorable weather.
- Even a three-way fungicide mixture could not prevent yield loss if the T2 application was applied too early at GS 39.
- For some programmes, a T2 applied at GS 49 was too late, suggesting the ideal timing for a T2 application is somewhere between GS 45-49.
- If a T2 was applied at GS 39, a T3 at GS 59 was sometimes required, but disease control, yields and economic returns of these treatments were no higher than well-balanced two-spray programmes.
- Using three-way mode-of-action mixtures at the right time can also reduce the amount of Rcc inoculum passed on to the next generation of seed.

# Fungicide programmes for disease wheat: products, timing, and rates

## Summary

An effective fungicide programme for autumn sown wheat is designed to balance disease control and corresponding yield with economic returns and pesticide stewardship. As part of an IPM approach it is the last line of defence. Cultivars provide the foundation of your disease management strategies.

A balanced fungicide programme limits the number of applications to those that pay their way, mixes mode-of-action groups, alternates products and uses the appropriate doses to slow the emergence of resistance and prolong the effective life of fungicides. This means that when picking a programme, you should think carefully about your cultivar, sowing date, stubble management, seasonal disease pressure conditions, whether you are irrigated or dryland and the target diseases.

Using this approach helps to make money and reduce pressure on both cultivars and chemistry. It does this by creating a complex genetic and chemical obstacle course that is much harder for the pathogen to overcome.

Supported by the Fungicide Resistance Industry Initiative, FAR has developed fungicide timing priorities, resistance management guidelines and decision trees to help growers decide what and when to spray.

## Fungicide application – timing, products and rates

Priorities for fungicides on autumn sown wheat are shown in Table 1.

**Table 1.** Prioritisation of autumn sown wheat fungicide programmes and timings.

| Priority 3 (Situational) | Priority 1 (Base Programme) | | Priority 2 (Seasonal) | Priority 4 (Highly situational) |
|---|---|---|---|---|
| GS 29 (T0) | GS 31 (T1) | GS 39 – 49 (T2) | GS 59 (T3) | GS 69-71 (T4) |

### T0 – GS 30-31 (End of tillering/start of stem elongation)
### Priority 3: Situational

Traditionally, a T0 has been used as a holding spray until T1 (GS 32) or as insurance against a delayed T1 application. However, recent sensitivity shifts to triazole fungicides in pathogen populations has seen a change in how fungicide applications are prioritised as we try to protect our chemistry.

At T0, a resistant cultivar can do the heavy lifting in the fight against disease, and while you may be tempted to shore up the cultivar with chemistry for "extra protection", FAR data suggest T0 applications rarely pay their way (even on susceptible cultivars and in high disease pressure seasons) and can also undermine cultivar resistance by increasing pathogen shifts to overcome both chemistry and cultivar.

Previous T0 applications featuring solo triazoles such as epoxiconazole (e.g. Opus®, Stellar®, AgPro Epizole, Fortify®), were seen as a relatively cheap way to set the crop up for the season. But when you dig into how often triazoles are used across the season, they can be used in excess of four times. (Figure 1).

We now know the number of triazoles applied in a season is just as important as the dose. Multiple exposures through repeated use will select for resistance in pathogen populations such as *Zymoseptoria tritici*. Thus, use of solo triazoles is particularly risky. Labels also stipulate not using more than three applications in any one season, including the seed treatment. As a result, T0 applications have become more complex, which inevitably means a T0 is more expensive than in the past.

To achieve a more balanced approach, consider treating the crop in response to developing disease. This means that if there is no significant pressure at the time, a T0 application could be skipped. The T0 Application Decision tree developed by FAR and the Fungicide Resistance Industry Initiative (page 11), can help you decide whether or not an intervention is necessary depending on your situation.

# management in autumn sown

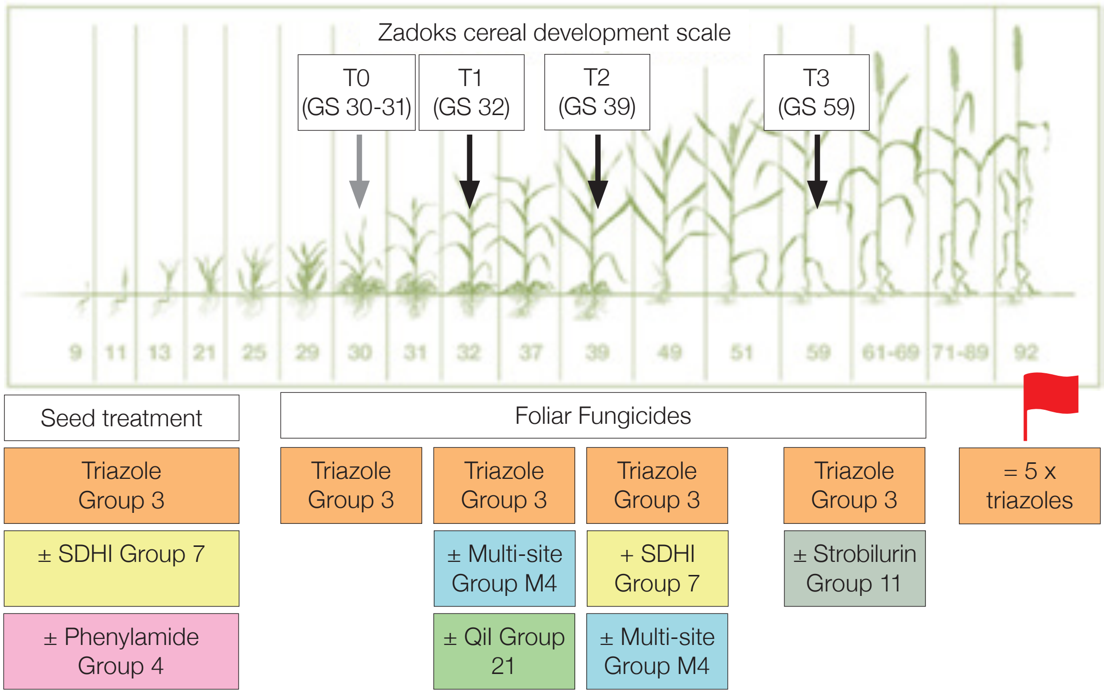


**Figure 1.** Seed treatment and foliar fungicide timings and the fungicide mode of action groups typically used at each timing.

If considering a T0, consider the following:

- **No application if appropriate (see Decision Support Tree, page 11).**
- **Stripe rust: Opus® (a.i. 125 g/L epoxiconazole, Group 3) (1.0 L/ha) + Amistar® (a.i. 250 g/L azoxystrobin, Group 11) (0.75 L/ha)**
- **Powdery mildew: Impulse® (a.i. 500 g/L spiroxamine, Group 5) (1.2 L/ha)**
- **STB: Bolide® (a.i. 50 g/L epoxiconazole and 225 g/L prochloraz, Group 3) (2.0 L/ha) ± Phoenix® (a.i. 500 g/kg folpet, Group M4) (1.5 L/ha)**

Where stripe rust is present, lead with a strobilurin (Group 11) such as azoxystrobin at an appropriate rate (e.g. Amistar®, AgPro Azoxystrobin, Atlantis® Flo, Avior 250 SC, Azoxystar®, Inspire®, Roxy®, Tazer®). Strobilurins must be applied with a mixing partner, and while we want to minimise the use of triazoles as much as possible, a rust active triazole such as epoxiconazole (e.g. Opus®, Stellar®, AgPro Epozole, Fortify®) at the full label rate could be an option. Bolide® (a.i. epoxiconazole + prochloraz, Group 3) could be considered for STB control. While it contains two triazoles, they have different cross-resistance pathways. Bolide® could be used in conjunction with the multi-site, folpet (Phoenix®, Valeo®, Group M4). Where powdery mildew (*Bllumeria graminis*) is the target pathogen, consider a specific mildew product such as spiroxamine (e.g. Impulse®, Spiral®, Group 5). Powdery mildew has resistance to strobilurin (Group 11) fungicides.

## Summary

### T1 – GS 32 (2nd node on main stem)
### Priority 1: Base programme

The nodal growth stage GS 32 coincides with leaf 3 emergence (the leaf two leaves below the flag). This is the first of the important top three leaves to emerge in the crop canopy (T1 + T2 are associated with 73% of yield). Protecting leaf 3 emergence should be part of your base programme (Priority 1, Table 1).

At this spray timing, balanced mixtures should be applied. Group 7 fungicides (SDHI) should only be included if the disease risk warrants it (see below).

While effective control can be challenging, T1 is the application time to manage common eyespot, with treatment based on triazole (Group 3) or triazole/SDHI (Group 3 + Group 7) based mixtures. Typically, the measures taken to manage common eyespot, will also manage other diseases such as STB. Internationally, mixtures that have included the triazole active ingredient prochloraz (found in Bolide®) have been successful.

When choosing the triazole (Group 3) to apply at T1, reduce the risk of cross-resistance)developing in pathogen populations by alternating the active ingredient you use with those used at T0 or other times in the season.

Solo triazoles such as epoxiconazole or prothioconazole (e.g. Proline®, AgPro Thiozole, Joust®, Prothago®, Vitalis®) should only be applied with the multi-site folpet.

**Low - moderate disease pressure**

- **Opus® (1.0 L/ha) + Phoenix® (1.5 L/ha)**
- **Proline® (a.i. 250 g/L prothioconazole, Group 3) (0.6 – 0.8 L/ha) + Phoenix® (1.5 L/ha)**
- **Revylution® (a.i. 100g/L mefentrifluconzole, Group 3) (1.5 L/ha) + Phoenix* (1.5 L/ha)**

Another option is fenpicoxamid (Group 21) (Questar™). This product is STB-specific and has a completely different mode-of-action. It could be an alternative to an SDHI (Group 7), however it has at least a moderate risk of resistance development, and should be applied with an appropriate mixing partner that has good efficacy against the target pathogen.

- **Questar™ (a.i. 50 g/L fenpicoxamid, Group 21) (1.5 L/ha) + Group 3**
  ***(Group 3 options: Proline® (0.6 – 0.8 L/ha), Prosaro® (1.0 L/ha), Kestrel® (1.0 – 1.25 L/ha), Bolide® (2.0 L/ha), Revylution® (1.5 L/ha).***
- **Fungicides listed above + Phoenix® (1.5 L/ha)**

Reduced sensitivity in triazole (Group 3) fungicides has seen the need for more robust strategies, such as the use of products that include a second triazole (Group 3) such as Prosaro® or Kestrel® (prothioconazole + tebuconazole) or Bolide® (epoxiconazole + prochloraz). Whilst from the same mode-of-action group, the active ingredients in these products have different cross-resistance pathways and so use of one, does not confer resistance to the other. Avoid mixing triazoles that have the same cross-resistance mechanisms (such as epoxiconazole + prothioconazole), as concurrent use of these active ingredients selects for resistance to both! Stacking triazoles can provide greater efficacy over solo triazoles and can help prolong the effective life of the fungicide, however, repeat application of the same stacked product in the same season still selects for resistance, so alternation of triazole active ingredients between applications remains an important resistance management strategy in these situations.

**Low - moderate or moderate - high disease pressure**

- **Kestrel® (a.i. 160 g/L prothioconazole + 80 g/L tebuconazole, Group 3) (1.0 – 1.25 L/ha)**
- **Prosaro® (a.i. 125 g/L prothioconazole + 125 g/L tebuconazole, Group 3) (1.0 L/ha)**
- **Bolide® (a.i. 50g/L epoxiconazole and 225 g/L prochloraz, Group 3) (2.0 L/ha)**
- **Fungicides listed above + Phoenix® (a.i. 500 g/kg folpet, Group M4) (1.5 L/ha)**

Resistance management guidelines for triazoles (Group 3), SDHIs (Group 7) and strobilurins (Group 11) have been developed with the support of the Fungicide Resistance Industry Initiative. Note that Prosaro® and Kestrel® applied at 1.0 L/ha contain 50% and 75% rates of prothioconazole, respectively. Bolide® applied at 2.0 L/ha contains 80% and 50% of epoxiconazole and prochloraz, respectively.

You should also consider the addition of the multi-site (Group M4) fungicide folpet (Phoenix®, Valeo® 500 SC) as a mixing partner at T1 timings across a range of disease pressures, especially if using solo triazoles as an anti-resistance strategy.

**Note:** Folpet has a label recommendation for a maximum of only two applications up to GS 39 and must be mixed with an alternative mode-of-action fungicide.

**Very high disease pressure**

Even under high disease pressure conditions, a triazole-based T1 application can still provide adequate control without having to use an SDHI (Group 7). In these situations, consider full label rates of 'stacked' triazoles such as Kestrel®, Prosaro® or Bolide® with or without the multi-site Phoenix® as outlined above. Alternatively, consider Questar™ applied at 2.0 L/ha, but again ensure an appropriate mixing partner with this product, as this non-SDHI (Group 21) option does not provide control of other diseases such as leaf rust.

If disease pressure is very high as a result of cultivar susceptibility, early sowing and wet weather, an SDHI (Group 7) will provide more robust protection. Consider mixtures of at least 75-100% triazoles (Group 3) with an appropriate SDHI (Group 7) rate. Recent FAR trials have found this rate to be closer to the full label rate.

A recent increase in the number of SDHI (Group 7) products available provides the opportunity to mix and match products between application timings and seasons. Many of these products such as Elatus™ Plus (a.i. benzovindiflupyr – SOLATENOL™), Imtrex® (a.i. fluxapyroxad), and Vimoy® Iblon® (a.i. isoflucpyram), which are sold as solo products and can be applied with any appropriate mixing partner. For these products, consider mixing partners that are based on a triazole (Group 3) or triazole + multi-site (Group 3 and M4). Options are outlined below:

- **Triazole and stacked triazole (Group 3) treatments as above for low-moderate disease pressure**
- **Caley® Iblon® (a.i. 50 g/L isoflucpyram and 100 g/L prothioconazole, Group 7 and 3) (1.5 L/ha) + Proline® (0.15 L/ha)**
- **Revystar® (a.i. 50 g/L fluxapyroxad and 100 g/L mefentrifluconazole, Group 7 and 3) (1.5 L/ha)**
- **Vimoy® Iblon® (a.i. 50 g/L isoflucpyram, Group 7) (1.5 L/ha) + Group 3**
  ***(Group 3 options: Opus® (0.75 – 1 L/ha) or Proline® (0.6 – 0.8 L/ha) or Prosaro® (1.0 L/ha) or Kestrel® 1.0 – 1.25 L/ha or Revylution® (1.5 L/ha))***
- **Elatus™ Plus (a.i. 100 g/L benzovindiflupyr, SOLATENOL™) (0.75 L/ha) + Group 3**
  ***(Group 3 options: Opus® (0.75 – 1 L/ha) or Proline® (0.6 – 0.8 L/ha) or Prosaro® (1.0 L/ha) or Kestrel® (1.0 – 1.25 L/ha), Bolide® (2.0 L/ha) or Revylution® (1.5 L/ha))***
- **Imtrex® (a.i. 62.5 g/L fluxapyroxad, Group 7) (1.25 L/ha) + Group 3**
  ***(Group 3 options: Opus® (0.75 – 1 L/ha) or Proline® (0.6 – 0.8 L/ha) or Prosaro® (1.0 L/ha) or Kestrel® (1.0 – 1.25 L/ha), Bolide® (2.0 L/ha) or Revylution® (1.5 L/ha))***
- **Questar™ (1.5 - 2.0 L/ha) + Group 3**
  ***(Group 3 options: Proline® (0.6 – 0.8 L/ha) or Prosaro® (1.0 L/ha) or Kestrel® (1.0 – 1.25 L/ha), Bolide® (2.0 L/ha) or Revylution® (1.5 L/ha))***
- **Fungicides listed above + Phoenix® (1.5 L/ha)**

Revystar® (a.i. fluxapyroxad and mefentrifluconazole, Group 7 + 3) and Caley® Iblon® (a.i. isoflucpyram and prothioconazole, Group 7 + 3) are sold as co-formulations. Revystar® applied at 1.5 L/ha contains a 100 g/L rate of mefentrifluconazole, while Caley® Iblon® applied at 1.5 L/ha contains a 75% label rate of prothioconazole.

Older products such as Aviator Xpro® (a.i. bixafen and prothioconazole) and Aviator® (a.i. fluxapyroxad and epoxiconazole) are also co-formulations of Group 7 and 3 chemistries but are better suited to lower disease pressure scenarios at T2. The triazole (Group 3) component of these older mixtures may need to be topped up.

**Note:** The new products Caley® Iblon® (isoflucpyram + prothioconazole) and Vimoy® Iblon® (isoflucpyram) may be used only once in a season.

# Summary

## T2 – GS 39 (Flag leaf fully emerged on main stem)
## Priority 1: Base programme

This is the most important growth stage for fungicide in all wheat crops, as the top three leaves have emerged on the main stem. These leaves are associated with around 73% of final yield. The flag leaf alone is associated with 43% of yield, making it the most important leaf, which is why T2 is often where growers spend the most money. Note that at this growth stage, flag leaves on the tillers are not fully emerged.

It is important to make sure that the time interval between the T1 spray and the flag leaf emergence (T2) spray does not exceed four weeks and that the flag leaf applications are applied when the flag leaf has emerged on the main stem as residual activity of the previous application wears thin.

Consider the triazole you will use as a base for this application, with 75-100% dose rates depending on whether your triazole is stacked or not. Alternate your triazole again at this application timing (e.g. if you used a product containing prothioconazole such as Proline®, Prosaro® or Kestrel® at T1, consider a product containing mefenitrifluconazole (Revylution®) or epoxiconazole (Opus® or Bolide®) at T2 or vice versa). The triazole you pick at each timing should be based on the needs of your crop.

Now is the time to prioritise using a SDHI (Group 7). Use appropriate rates of SDHI for your cultivar. If you have used an SDHI at T1, choose a different one at T2.

**Moderate - high disease pressure**

- **Caley® Iblon®) (1.5 L/ha) + Proline® (0.15 L/ha)**
- **Revystar® (1.5 L/ha)**
- **Vimoy® Iblon® (1.5 L/ha) + Group 3**
  ***(Group 3 options: Opus® (0.75 – 1 L/ha) or Proline® (0.6 – 0.8 L/ha) or Prosaro® (1.0 L/ha) or Kestrel® 1.0 – 1.25 L/ha or Revylution® (1.5 L/ha))***
- **Elatus™ Plus (0.75 L/ha) + Group 3**
  ***(Group 3 options: Opus® (0.75 – 1 L/ha) or Proline® (0.6 – 0.8 L/ha) or Prosaro® (1.0 L/ha) or Kestrel® (1.0 – 1.25 L/ha), Bolide® (2.0 L/ha) or Revylution® (1.5 L/ha))***
- **Imtrex® (1.25 L/ha) + Group 3**
  ***(Group 3 options: Opus® (0.75 – 1 L/ha) or Proline® (0.6 – 0.8 L/ha) or Prosaro® (1.0 L/ha) or Kestrel® (1.0 – 1.25 L/ha), Bolide® (2.0 L/ha) or Revylution® (1.5 L/ha))***
- **Fungicides listed above + Phoenix® (1.5 L/ha)**
- **Fungicides listed above + Questar™ (1.5 – 2.0 L/ha)**

**Low disease pressure**

FAR trials in South Canterbury conducted since 2014 have shown the use of the most expensive fungicide programmes is not always cost effective in dryland situations, especially when using a more resistant cultivar. The exception was in 2016, where dryland crops behaved more like those grown under irrigation. However, as anti-resistance strategies are based on more costly balanced mixtures, using a robust T1 + T2 base programme may provide sufficient disease control through to harvest, reducing costs further down the line.

## T3 – GS 59-65 (Ear emergence – flowering)
## Priority 2 (Seasonal)

FAR trials have demonstrated repeatedly that the majority of disease control, yield and economic returns are associated with T1 + T2 applications. However, the greatest balance from a fungicide programme is often achieved by adding a T3 spray. A T3 application is timed to protect the 22% of yield associated with the leaf sheath and ear.

T3 is considered Priority 2, used in response to the season and the specific situation in your paddock. The T3 is based on triazoles, selection of which will depend on whether your target disease is STB or leaf rust. If it is possible, you should also consider a triazole that has not yet featured in your fungicide programme.

As at T1, try to avoid using solo triazoles. A stacked triazole, or a triazole mixed with another mode-of-action group such as a strobilurin such as pyraclostrobin (e.g. Comet®, Convoy™, Pyrax®), can help. The triazole component of the mixture will provide coverage for STB, while a strobilurin will protect against leaf rust. Remember, the strobilurins will not control STB in New Zealand. The multi-site folpet (Phoenix® has a final application timing of GS 39 in wheat, so cannot be used at T3.

Where STB and head infection caused by *Fusarium spp*. are the key target diseases, consider prothioconazole mixed with tebuconazole (e.g. Prosaro® or Kestrel®), or products like Bolide®, which contain the active ingredient prochloraz in addition to epoxiconazole. Effective control of *Fusarium* in the head is difficult to achieve, even when fungicide is applied at the most effective timing of GS 59-61 (ear emergence – early flowering). Applications targeting *Fusarium* after GS 61 will not be effective.

**Moderate-high disease pressure**

- **Prosaro® (1.0 L/ha)**
- **Kestrel® (1.0 – 1.25 L/ha)**
- **Opus® (1.0 L/ha) + Comet® (a.i. 250 g/L pyraclostrobin, Group 11) (0.4 – 0.8 L/ha) or Amistar® (0.75 L/ha)**
- **Revylution® (1.5 L/ha) + Comet® (0.4 – 0.8 L/ha) or Amistar® (0.75 L/ha)**
- **Bolide® (2.0 L/ha)**

**Very high disease pressure**

Yield response and economic returns for T3 fungicides are less than for T1 + T2, however, where STB has been encouraged by wet weather post-flag, consider the same applications as outlined for the flag leaf, but only if one SDHI has been applied and leaf rust is also present.

Where two SDHIs have been applied and cultivars are susceptible to both leaf rust and STB, use the options outlined above. Remember: Do not apply three SDHIs. Also, prothioconazole (e.g. Proline®) is weaker on leaf rust, so choose accordingly.

**In dryland or low-disease pressure scenarios**

Where disease pressure is low, a T3 should be considered optional, dependent on rainfall from flag leaf until ear emergence.

- **No application if appropriate**
- **Opus® (0.25 L/ha) + Amistar® (0.25 L/ha)**

## T4 – GS 69-72 (Post flowering)<br>Priority 4: Highly situational

A recent resurgence of late-season disease has seen renewed interest in post-flowering (GS 69-72 (T4)) fungicide applications. However, FAR trials have shown little or no benefit in terms of disease control, yield or financial return of applications at this time when compared with a programme that finishes at T3. Think carefully about the likely return-on-investment as well as the implications for resistance management before going ahead with a T4 spray.

If a T4 is important to you, consider further that mixtures based on epoxiconazole (Opus® - Group 3) and azoxystrobin (Amistar®- Group 11) or tebuconazole (e.g. Folicur®, Compass®, Hornet®, Rebuke) (which have withholding periods of 42, 35 and 49 days respectively) were no better than a T3 (ear emergence) application of Opus® + Comet® (Group 3 + 11) or Prosaro® (Group 3) when leaf rust and STB were the target.

**Irrigated crops only (highly season dependent)**

- **No application if appropriate**
- **Opus® (0.25 L/ha) + Amistar® (0.25 L/ha)**
- **Folicur® (a.i. 420 g/L tebuconazole, Group 3) (0.44 L/ha) + Amistar® (0.25 L/ha)**

# Summary

FAR and the Fungicide Resistance Industry Initiative have developed a T4 Application Decision Tree to help see page 11.

**Notes:**

**The rates outlined in this strategy assume optimal application. Late sprays, where disease pressure is high, may require higher rates. Use of rates lower than the full label rates are carried out at the growers' risk.**

**Be extremely mindful of withholding periods when considering late fungicides.**

**In some situations, and in some seasons, dryland sites may be more equivalent to irrigated sites. In all situations, monitor rainfall between GS 30 – GS 69 (early stem elongation – end of flowering). For dryland crops where rainfall is well above average, consider irrigated strategies as well as dryland options.**

**Will I benefit from a T0?**

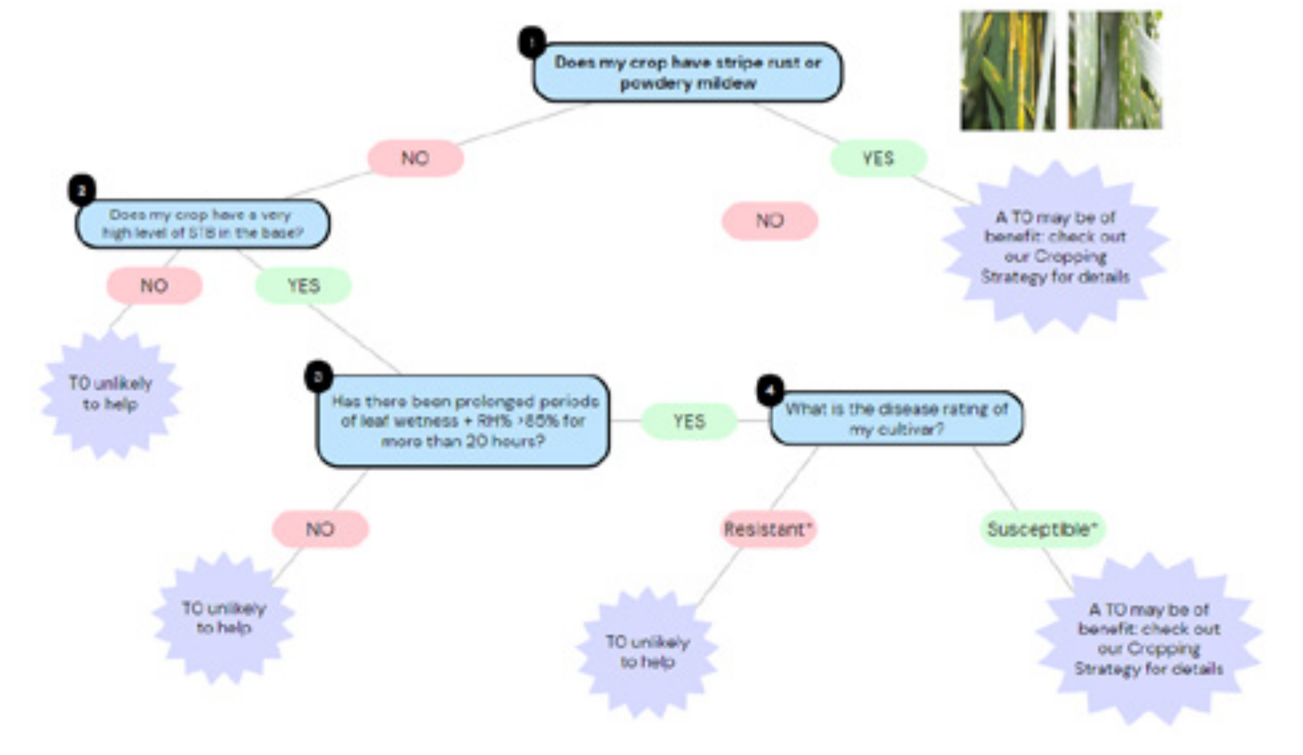


**Figure 5.** GS 30-31 (T0) Decision Tree. *Check the latest CPT ratings for your cultivar.

**Will I benefit from a T4?**

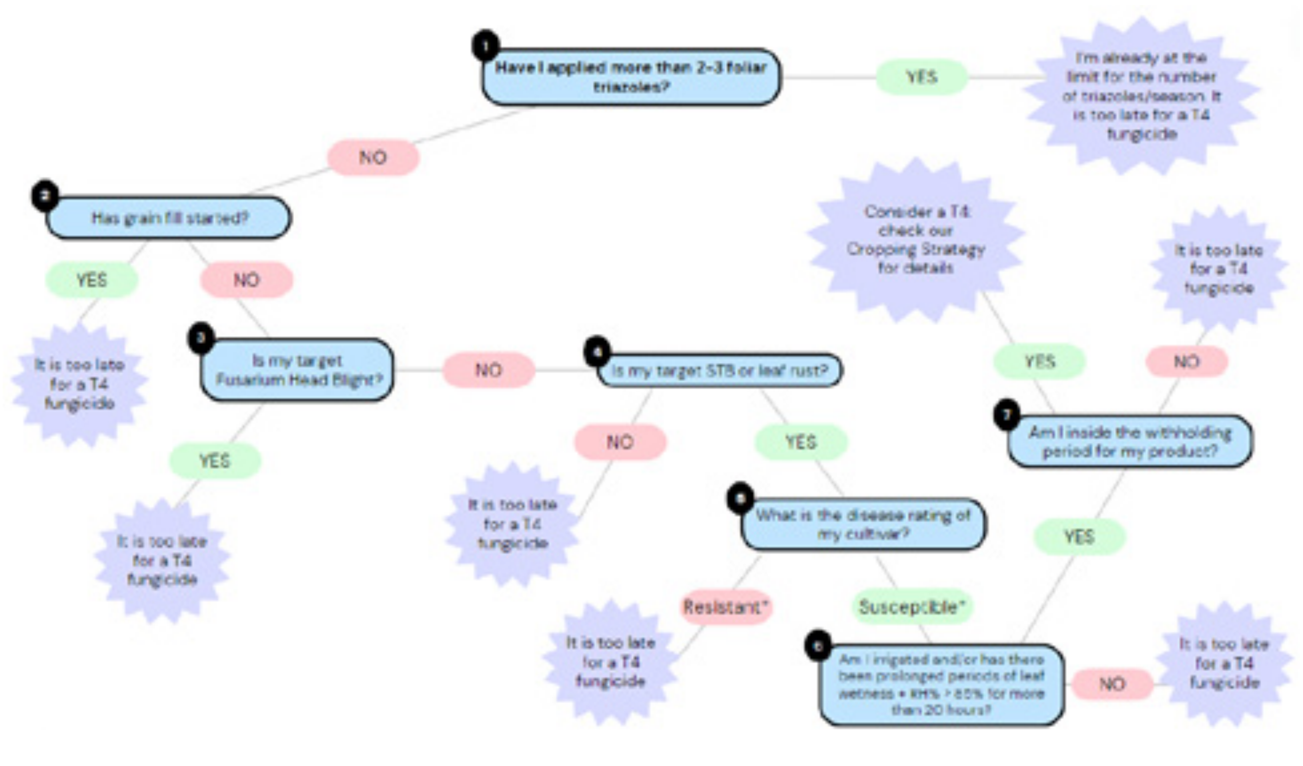


**Figure 6.** GS 69-71 (T4) Decision Tree. *Check the latest CPT ratings for your cultivar.

# Fungicide programmes for disease barley: products, timing, and rates

## Summary

As with wheat, an integrated approach to autumn sown barley disease control is preferred. However, with Ramularia leaf spot (RLS), the lack of associated cultivar resistance, and the emergence of reduced sensitivity to strobilurin (Group 11) and SDHI (Group 7) fungicides make an integrated strategy challenging.

Management of barley diseases increasingly relies on using mixtures of fungicides with different mode-of-action groups. Experimental-only FAR trial data and earlier sensitivity testing carried out by Plant & Food Research as part of the Sustainable Farming Fund project on Ramularia have found that each mode-of-action will have varying degrees of efficacy depending on the target disease (Figure 1).

On-farm, all products must be applied in mixtures. Mixtures improve the efficacy of the individual component chemistries and offer more broad-spectrum control of diseases such as scald, leaf rust and net blotch. Net blotch remains a disease to watch because of the potential for resistance development in some fungicide mode-of-action groups, which is the case overseas.

| | RLS | Net blotch | Leaf Rust | Scald |
|---|---|---|---|---|
| Triazole (Group 3) | Orange | Green | Yellow | Green |
| Multi-site (Group M4) | Green | Yellow | Orange | Orange |
| Strobilurin (Group 11) | Orange | Green | Green | Green |
| SDHI (Group 7) | Orange | Green | Green | Yellow |

**Figure 1.** Efficacy of fungicide mode-of-action groups when applied as solo products on the main diseases in autumn sown barley. Products must be applied in mixtures. Green = high efficacy; Yellow = some efficacy (check the product label); Orange = reduced efficacy.

## Fungicide application – timing, products and rates

### General considerations

Autumn barley tends to be more susceptible to diseases than spring sown barley because of its longer growing season and the tendency for wet weather diseases such as scald (*Rynchosporium commune*) to build up over winter. Therefore, an autumn sown barley strategy should be based on at least two foliar fungicide applications from the start of stem elongation (GS 31), even if seed treatment (e.g. Systiva® a.i. fluxapyroxad, SDHI – Group 7) has been used. Priorities for fungicides on autumn sown barley are shown in Table 1.

**Table 1.** Prioritisation of autumn sown barley fungicide programmes and timings.

| Priority 3 (Situational) | Priority 1 (Base Programme) | | Priority 2 (Seasonal) |
|---|---|---|---|
| GS 29 (T0) | GS 31 (T1) | GS 39 – 49 (T2) | GS 59 (T3) |

## Seed treatment

Seed treatments form the first line of defence against many soil and seedborne pathogens, with some providing control of early foliar diseases. RLS is seedborne, but is not controlled effectively by seed treatments used to control other barley pathogens. Care should be taken with any farm-saved or certified seed, especially where high levels of RLS have been previously reported in the field.

If using a seed treatment such as Systiva®, remember it counts towards one of the two SDHI applications allowed per season. This limits you to only one foliar SDHI application during the season. If a SDHI seed treatment is used, the optimum time to add a foliar SDHI to the mix would be at GS 39-49 (T2) because of the activity of these fungicides against leaf rust.

# management in autumn sown

**Table 2.** Fungicide seed treatments of barley.

| Product | Active ingredient | Chemical Group | Mode of Action Group | Diseases controlled |
|---|---|---|---|---|
| Kinto® Duo | 20 g/L triticonazole +<br>60 g/L prochloraz | Triazole<br>Triazole | 3<br>3 | Covered smut, loose smut, Fusarium, net blotch, scald. |
| Raxil® Star | 20 g/L fluopyram +<br>100 g/L prothioconazole +<br>60 g/L tebuconazole | SDHI<br>Triazole<br>Triazole | 7<br>3<br>3 | Covered smut, loose smut, leaf stripe, seed borne net blotch, seedling blight, true snow mould and foot rot caused by *Fusarium spp.* and *Gerlachia nivalis.* |
| Rancona® Dimension | 25 g/L ipconazole +<br>20 g/L metalaxyl | Triazole<br>Phenylamide | 3<br>4 | Loose smut, covered smut, bunt, seed borne disease and seedling rot diseases inc. *Rhizoctonia*, *Pythium*, *Fusarium spp.*, *M. nivale.* |
| Vitaflo® | 20 g/L carboxin +<br>200 g/L thiram | SDHI<br>Multi-site | 7<br>M03 | Covered smut, loose smut, net blotch, leaf stripe and soilborne seed and seedling rot diseases including those caused by *Fusarium*. |
| Systiva® | 333 g/L fluxapyroxad | SDHI | 7 | Covered smut, loose smut, leaf stripe, leaf rust, net blotch, scald, powdery mildew. |
| Capri® | 25 g/L tebuconazole | Triazole | 3 | Loose and covered smut. |

## T0 – GS 29 (Late tillering)
## Priority 3: Situational

FAR trials have shown no disease control, yield or economic benefit from T0 application timing. Traditionally, it has been used as an optional holding spray when scald pressure is high in early spring. It is also considered if leaf rust is out of control or high amounts of net blotch are visible. However, care should be taken as fungicide resistance to both triazole (Group 3) and SDHI (Group 7) fungicides is widespread in the pathogens responsible for net form and spot form of net blotch in Australia, suggesting it could emerge in New Zealand. Rapid changes in some pathogen populations mean that reduced exposure to chemistry may be the only way to slow resistance development. Therefore, with the combined lack of return-on-fungicide investment and associated resistance risks, a T0 should be considered a Priority 3 application – situational - only.

The two most likely scenarios for needing a late-tillering spray are where barley is grown following barley or where barley is sown early. It has tended to be more useful in dryland crops on lighter soils where early leaf loss is relatively more important (since there is less green leaf retention later in the season). If a T0 is required, consider the triazole (Group 3) prothioconazole (e.g. Proline®, Pilot™, Vitalis®, Joust®, Prothago® and Agpro Thiozole) in a mixture with either carbendazim (Group 1) (e.g. Protek®, Agpro Guardian, Chief®, Carbenz, Goldazim® 500 SC, MBC 500 FLO) or a strobilurin (Group 11) such as picoxystrobin (Acanto®), pyraclostrobin (e.g. Comet®, ConvoyTM, Pyrax®) or azoxystrobin (e.g. Amistar®, AgPro Azoxystrobin, Atlantis® Flo, Avior 250 SC, Azoxystar®, Inspire®, Roxy®, Tazer®).

- **No application if appropriate**
- **Proline® (a.i. 250 g/L prothioconazole, Group 3) (0.2 – 0.4 L/ha) and either Protek® (a.i. 500 g/L carbendazim, Group 1) (0.5 L/ha) or Acanto® (a.i. 250 g/L picoxystrobin, Group 11) (0.25 – 0.5 L/ha) or Comet® (a.i. 250 g/L pyraclostrobin, Group 11) (0.4 – 0.8 L/ha) or Amistar® (a.i. 250 g/L azoxystrobin, Group 11) (0.5 – 0.75 L/ha)**

**Note:** Do not omit the T1 and T2 sprays if a T0 is applied. Apply a maximum of two strobilurins (Group 11) in a season.

# Summary

## T1 – GS 31 (Pseudo stem erect - first node)
## Priority 1: Base programme

The nodal growth stage GS 31 coincides with Leaf 4 emergence (three leaves below the flag). This is the first of the important leaves to emerge in the crop canopy and is considered Priority 1 (a base programme) (Table 1). At this spray timing, barley disease management programmes are based on mixing modes-of-action to improve the efficacy of mix components and offer more broad-spectrum activity against a range of barley diseases. While a strong programme for RLS is important across both T1 and T2 applications, T1 can often have a scald or net blotch focus. Since 2017, FAR trials have shown the addition of folpet (Group M4) (e.g. Phoenix®, Valeo®) as a mixing partner to a mix of either a triazole + SDHI or triazole + strobilurin has given improved control of RLS and increasingly yield when compared with triazoles alone or triazoles mixed with SDHIs.

Therefore, the products you select for your mixture at a given application timing, should be based on a triazole (Group 3) + multi-site (Group M4) base, with the third mixing partner a SDHI (Group 7) or strobilurin (Group 11) selected based on the pressure and risks to your crop (Figure 1 )

A mixture of prothioconazole plus folpet (i.e. Proline® + Phoenix®) has a weakness against leaf rust. Leaf rust has been present in few FAR autumn sown barley trials over recent years. However, if leaf rust is present, or the cultivar is relatively susceptible to leaf rust, consider the addition of a strobilurin (Group 11) such as Acanto® or an SDHI (Group 7) such as Seguris Flexi® (a.i. 125 g/L isopyrazam), which have been successfully used in FAR trials. Other strobilurin (Group 11) options include Comet® (and generics), Amistar® (and generics) or Delaro® (a.i. 175 g/L prothioconazole + 150 g/L trifloxystrobin, Group 3 + 11).

**Where leaf rust is not of concern:**

- **Proline® (0.4 – 0.8 L/ha) + Phoenix® (a.i. 500 g/kg folpet, Group M4) (1.5 L/ha)**
- **Revylution® (a.i. 100 g/L mefenitrifluconazole, Group 3) (1.5 L/ha) + Phoenix® (1.5 L/ha)**

**Where leaf rust is of concern:**

- **Kestrel® (a.i. 160 g/L prothioconazole + 80 g/L tebuconazole) (1.0 L/ha) + Phoenix® (1.5 L/ha)**
- **Proline® (0.4 – 0.8 L/ha) + Acanto® (0.25 – 0.5 L/ha) + Phoenix® (1.5 L/ha)**
- **Proline® (0.4 – 0.8 L/ha) + Seguris Flexi® (a.i. 125 g/L isopyrazam, Group 7)) (0.3 – 0.6 L/ha) + Phoenix (1.5 L/ha)**
- **Revystar® (a.i. 50 g/L fluxapyroxad + 100 g/L mefenitrifluconazole, Group 7 + 3) + Phoenix® (1.5 L/ha)**
- **Miravis Flexi® (a.i. 62.5 g/L pydiflumetofen (ADEPIDYN®), Group 7) + Proline® (0.4 – 0.8 L/ha) + Phoenix® (1.5 L/ha)**

**Note:** Apply a maximum of two strobilurins (Group 11) in a season.

## T2 – GS 39-49 (Flag leaf fully emerged – awns visible)
## Priority 1: Base programme

This is an important fungicide timing, as it provides coverage of leaves two and three, which along with leaf four (protected by the T1 application) are the “money leaves” of a barley crop along with the flag leaf sheath, which is of greater importance than the barley flag leaf itself. Prior to 2020, T2 applications were suggested to coincide with GS 39, as the Phoenix® label did not extend past this growth stage. Since then, the label has been extended, providing more flexibility when applying a T2 spray (between GS 39 – 49). This later GS 49 application has the advantage of applying fungicide to the flag sheath, which is yet to emerge at GS 39. However, the benefit should be considered against ensuring the gap between the T1 and T2 does not exceed 21-28 days.

In recent seasons, Revystar® (a.i. 50 g/L fluxapyroxad + 100 g/L mefenitrifluconazole, Group 7 + 3) + Phoenix® has provided consistent control of RLS, along with strong yields and economic returns. This has been largely driven by the triazole component, which is now available as Revylution® (a.i. 100 g/L mefenitrifluconazole). The newly released SDHI, Miravis® Flexi (a.i. 62.5 g/L pydiflumetofen (ADEPIDYN®), Group 7), applied in a three-way mix with Proline® and Phoenix® has also proven to have strong activity against RLS, which is different to the other SDHIs, which have limited activity against the disease and will need careful management to prevent resistance development. Miravis® Flexi also has activity against scald.

Vimoy® Iblon® (a.i. 50 g/L isoflucpyram, Group 7) applied in a three-way mix with Proline® and Phoenix® is also an option at T2, but it has tended to be weaker on RLS than either Revystar® + Phoenix® or Miravis® Flexi three-way mixture. This is consistent with the reduced sensitivity of Ramularia collo-cygni (the pathogen responsible for RLS) isolates to SDHIs.

As with the T1 approach, fungicide mixtures should be considered based on mixtures of up to three mode-of-action groups. Often T2 has a strong RLS focus. FAR trial data has featured strobilurins applied as Acanto®. Other options are available and outlined in the T1 approach below.

**Where leaf rust is not of concern:**

- **Proline® (0.4 – 0.8 L/ha) + Phoenix® (a.i. 500 g/kg folpet, Group M4) (1.5 L/ha)**
- **Revylution® (a.i. 100 g/L mefenitrifluconazole, Group 3) (1.5 L/ha) + Phoenix® (1.5 L/ha)**

**Where leaf rust is of concern:**

- **Kestrel® (a.i. 160 g/L prothioconazole + 80 g/L tebuconazole) (1.0 L/ha) + Phoenix® (1.5 L/ha)**
- **Proline® (0.4 – 0.8 L/ha) + Acanto® (0.25 – 0.5 L/ha) + Phoenix® (1.5 L/ha)**
- **Proline® (0.4 – 0.8 L/ha) + Seguris Flexi® (a.i. 125 g/L isopyrazam, Group 7)) (0.3 – 0.6 L/ha) + Phoenix (1.5 L/ha)**
- **Revystar® (a.i. 50 g/L fluxapyroxad + 100 g/L mefenitrifluconazole, Group 7 + 3) + Phoenix® (1.5 L/ha)**
- **Miravis Flexi® (a.i. 62.5 g/L pydiflumetofen (ADEPIDYN®), Group 7) + Proline® (0.4 – 0.8 L/ha) + Phoenix® (1.5 L/ha)**
- **Vimoy® Iblon® (a.i. 50 g/L isoflucpyram, Group 7) (1.5 L/ha) + Proline® (0.4 L/ha) + Phoenix® (1.5 L/ha)**

**Note:** Apply a maximum of two strobilurins (Group 11), SDHI (Group 7) or multi-site (Group M4) in a season.

## T3 – GS 59 head emergence (Ear emergence – early flowering)
## Priority 2: Seasonal

In some seasons, such in 2022-23, disease control, yield and economic returns are compromised by a 2-spray programme, particularly if the T2 application is applied at the GS 39 end of the T2 window (Table 2). In these situations, a T3 (GS 59) can be beneficial. However, a well-timed, well-balanced 2-spray programme is as high-yielding and profitable as a three-spray programme (again demonstrated in 2022-23 and 2023-24). This suggests a T3 application can be considered a Priority 2 spray (Seasonal or situational), especially when an early T2 has been applied.

Data from FAR trials suggests that higher fungicide rates provide better protection against disease in irrigated crops, particularly leaf rust, but this is not always the case in dryland scenarios.

A T3, like the T1 and T2, will have a triazole base, but by the time the crop reaches T3, a number of restrictions limit the number of available fungicide options. The multi-site Phoenix® has a maximum of two applications in a season and can be applied no later than GS 59. Thus, if Phoenix® featured at both T1 and T2, it cannot be used at T3. Both SDHIs (Group 7) and strobilurins (Group 11) also have a limit of two applications in a season.

**Where two SDHIs (Group 7) have been applied earlier:**

- **Proline® (0.2 L/ha) + Seguris® Flexi® (0.3 L/ha)**

**Where two strobilurins (Group 11) have been applied earlier:**

- **Proline® (0.2 L/ha) + Acanto® (0.25 L/ha)**

**Notes:**
**The rates outlined in this strategy assume optimal timing of application. Late sprays, where disease pressure is high, may require higher rates but do not exceed the rate stated on the label. Use of rates lower than the full label rates are carried out at the growers' risk.**

**Be extremely mindful of withholding periods when considering late fungicides.**

**In some situations, and in some seasons, dryland sites may be more equivalent to irrigated sites. In all situations, monitor rainfall between GS 30, 39-49 and GS 59 (early stem elongation – ear emergence). For dryland crops where rainfall is well above average, consider irrigated strategies as well as dryland options.**

# Fungicide programmes for disease barley: products, timing, and rates

## Summary

Optimum fungicide timings in spring sown barley generally mirror those observed in FAR trials on autumn sown barley. However, five key differences have been observed:

1. Spring sowing reduces disease pressure, allowing a reduction in fungicide use.
2. Later sown crops (October onwards) develop very quickly, with a short grain fill period, reducing the need for fungicide persistence.
3. Rapid development makes hitting key fungicide timings more challenging, particularly in later sown crops in the North Island.
4. In Hawke's Bay and Wairarapa, where dryland crops are sown later, fungicide applications produce a relatively small return on investment; programmes should be tailored accordingly.
5. In Canterbury, leaf rust is traditionally more prevalent in spring barley trials, this is reflected in the most effective spray programmes.

## Fungicide application – timing, products and rates

### General considerations

Spring sown barley tends to be less susceptible to disease than autumn sown barley because of its shorter growing season. For instance, development of spring barley is often so rapid that symptoms of RLS and rapid senescence fail to appear until after the grain-fill period. This reduces the impact of RLS on yield.

T1 is often considered a net blotch spray, and T2 a RLS spray. The two-spray programme starts at first node (GS 31) in earlier sown crops (before October) and at row closure (GS 23 – 30) in later sown crops (October onwards). FAR has not yet placed priorities on T1 and T2 applications because of the rapid nature of spring barley development. Like autumn-sown barley, spring barley fungicide programmes are based on mixtures of fungicides with different mode-of-action groups (Figure 1).

Given the small return on investment of fungicide in spring barley, reduced-input programmes based on the use of a lower number of applications, fungicide mixtures and appropriate rates are worthy of consideration. Reduced input programmes feature in FAR trials this season (2024/25).

| | RLS | Net blotch | Leaf Rust | Scald |
|---|---|---|---|---|
| Triazole (Group 3) | Orange | Green | Yellow | Green |
| Multi-site (Group M4) | Green | Yellow | Orange | Orange |
| Strobilurin (Group 11) | Orange | Green | Green | Green |
| SDHI (Group 7) | Orange | Green | Green | Yellow |

**Figure 1.** Efficacy of fungicide mode-of-action groups when applied as solo products on the main diseases in autumn sown barley. Products must be applied in mixtures. Green = high efficacy; Yellow = some efficacy (check the product label); Orange = reduced efficacy.

### Seed treatment

Like autumn barley, seed treatments remain the first line of defence against many soil and seedborne pathogens, with some providing control of early foliar diseases (Table 1). RLS is seedborne, but is not controlled effectively by seed treatments used to control other barley pathogens. Care should be taken with any farm-saved or certified seed, especially where high levels of RLS have been previously reported in the field.

# management in spring sown

Remember that a seed treatment such as Systiva® counts towards one of the two SDHI applications allowed per season. This limits you to only one foliar SDHI application during the season. If a SDHI seed treatment is used, the optimum time to add a foliar SDHI to the mix would be at GS 39-49 (T2) because of the activity of these fungicides against leaf rust.

**Table 2.** Fungicide seed treatments of barley.

| Product | Active ingredient | Chemical Group | Mode of Action Group | Diseases controlled |
|---|---|---|---|---|
| Kinto® Duo | 20 g/L triticonazole +<br>60 g/L prochloraz | Triazole<br>Triazole | 3<br>3 | Covered smut, loose smut, Fusarium, net blotch, scald. |
| Raxil® Star | 20 g/L fluopyram +<br>100 g/L prothioconazole +<br>60 g/L tebuconazole | SDHI<br>Triazole<br>Triazole | 7<br>3<br>3 | Covered smut, loose smut, leaf stripe, seed borne net blotch, seedling blight, true snow mould and foot rot caused by *Fusarium spp.* and *Gerlachia nivalis.* |
| Rancona® Dimension | 25 g/L ipconazole +<br>20 g/L metalaxyl | Triazole<br>Phenylamide | 3<br>4 | Loose smut, covered smut, bunt, seed borne disease and seedling rot diseases inc. *Rhizoctonia*, *Pythium*, *Fusarium spp.*, *M. nivale.* |
| Vitaflo® | 20 g/L carboxin +<br>200 g/L thiram | SDHI<br>Multi-site | 7<br>M03 | Covered smut, loose smut, net blotch, leaf stripe and soilborne seed and seedling rot diseases including those caused by *Fusarium*. |
| Systiva® | 333 g/L fluxapyroxad | SDHI | 7 | Covered smut, loose smut, leaf stripe, leaf rust, net blotch, scald, powdery mildew. |
| Capri® | 25 g/L tebuconazole | Triazole | 3 | Loose and covered smut. |

## T1– GS 23-30 (late sown crops); GS 31 (early sown crops)

As with autumn sown barley, the addition of folpet (Group M4) (e.g. Phoenix®, Valeo®) to a mix of either a triazole + SDHI (Group 3 + 7) or triazole + strobilurin (Group 3 + 11) has given the most effective control of RLS. These mixtures provide a broad spectrum of activity against the range of common barley diseases (Figure 1).

Irrigated or early sown dryland crops:

- **Proline® (a.i. 250 g/L prothioconazole, Group 3) (0.2 – 0.4 L/ha) + Seguris Flexi® (a.i. 125 g/L isopyrazam, Group 7) (0.3 – 0.6 L/ha) + Phoenix® (a.i. 500 kg/g folpet, Group M4) (1.5 L/ha)**
- **Proline® (0.2 – 0.4 L/ha) + Acanto® (a.i. 250 g/L picoxystrobin, Group 11) + Phoenix® (1.5 L/ha)**
- **Kestrel® (a.i. 160 g/L prothioconazole + 80 g/L tebuconazole ,Group 3) (1.0 L/ha) + Phoenix® (1.5 L/ha)**
- **Revystar® (a.i. 50 g/L fluxapyroxad + 100 g/L mefenitrifluconazole, Group 7 + 3) (1.5 L/ha) + Phoenix® (1.5 L/ha)**
- **Revylution® (a.i. 100 g/L mefenitrifluconazole, Group 3) (1.5 L/ha) + Phoenix® (1.5 L/ha)**
- **Miravis® Flexi® ( a.i. 62.5 g/L pydiflumetofen (ADEPIDYN®), Goup 7) (1.2 L/ha) + Proline® (0.2 – 0.4 L/ha) + Phoenix® (1.5 L/ha)**
- **Vimoy® Iblon® (a.i. 50 g/L isoflucpyram, Group 7) (1.5 L/ha) + Proline® (0.2 – 0.4 L/ha) + Phoenix® (1.5 L/ha)**

## Summary

For dryland crops, where disease pressure has been historically low:

- **Proline® (0.2 L/ha) + Protek® (a.i. 500 g/L carbendazim, Group 1) (0.5 L/ha) for scald**
- **Proline® (0.2 L/ha) + Phoenix® (1.5 L/ha) (if both scald AND RLS are expected)**

These combinations are traditionally weak on leaf rust, so if this disease is of concern follow the irrigated strategies above. FAR trial data using strobilurins (Group 11) has featured Acanto®. Other options include pyraclostrobin (e.g. Comet®, ConvoyTM, Pyrax®) or azoxystrobin (e.g. Amistar®, AgPro Azoxystrobin, Atlantis® Flo, Avior 250 SC, Azoxystar®, Inspire®, Roxy®, Tazer®).

### T2 - GS 39-49 (Flag leaf fully emerged, awns visible)

The T2 application timing in spring barley crops is as important as in autumn crops; the challenge is getting the timing right. Depending on sowing date and crop development, there can be as little as two weeks between T1 and T2, and the T2 window between GS 39 and GS 49 can be as short as a few days. Fungicide options for the T2 timing in spring barley are the same as for autumn sown barley. A later GS 49 application has the advantage of applying the fungicide to the flag leaf sheath, which is yet to emerge at GS 39. However, the benefit has to be considered against ensuring the gap between T1 and T2 does not exceed 21-28 days.

As with the T1 approach, fungicide mixtures should be considered based on up to three mode-of-action groups. Often T2 has a strong RLS focus. FAR trial data has featured Acanto® as the strobilurin. Other options are available and outlined in the T1 approach above. In crops with lower disease pressure, particularly later sown ones, such as in parts of Wairarapa, Manawatu, Hawke's Bay/Rangitikei and some drier, inland parts of Southland, lower input fungicide programmes are more cost effective.

For irrigated crops or early disease prone dryland crops where leaf rust is NOT of concern:

- **Proline® (0.4 – 0.8 L/ha) + Phoenix® (1.5 L/ha)**
- **Revylution® (1.5 L/ha) + Phoenix® (1.5 L/ha)**

For irrigated or early disease prone dryland crops where leaf rust IS a concern:

- **Kestrel® (1.0 L/ha) + Phoenix® (1.5 L/ha)**
- **Proline® (0.4 – 0.8 L/ha) + Acanto® (0.25 – 0.5 L/ha) + Phoenix® (1.5 L/ha)**
- **Proline® (0.4 – 0.8 L/ha) + Seguris Flexi® (a.i. 125 g/L isopyrazam, Group 7) (0.3 – 0.6 L/ha) + Phoenix (1.5 L/ha)**
- **Revystar® + Phoenix® (1.5 L/ha)**
- **Miravis Flexi®, Group 7) + Proline® (0.4 – 0.8 L/ha) + Phoenix® (1.5 L/ha)**
- **Vimoy® Iblon® (1.5 L/ha) + Proline (0.4 – 0.8 L/ha) + Phoenix® (1.5 L/ha)**

For dryland crops or where disease pressure has been historically low:

- **Proline® (0.2 – 0.4 L/ha) + Seguris Flexi® (0.3 – 0.6 L/ha) + Phoenix® (1.5 L/ha)**
- **Proline® (0.2 – 0.4 L/ha) + Seguris Flexi® (0.3 – 0.6 L/ha) + Phoenix® (1.5 L/ha)**
- **Kestrel® (1.0 L/ha) + Phoenix® (1.5 L/ha)**
- **Revystar® (1.5 L/ha) + Phoenix® (1.5 L/ha)**
- **Revylution® (1.5 L/ha) + Phoenix® (1.5 L/ha)**
- **Miravis® Flexi® (1.2 L/ha) + Proline® (0.2 – 0.4 L/ha) + Phoenix® (1.5 L/ha)**
- **Vimoy® Iblon® (1.5 L/ha) + Proline® (0.2 – 0.4 L/ha) + Phoenix® (1.5 L/ha)**

**Note:** Apply a maximum of two strobilurins (Group 11), SDHI (Group 7) or multi-site (Group M4) in a season.

**Notes:**

**The rates outlined in this strategy assume optimal timing of application. Late sprays, where disease pressure is high, may require higher rates but do not exceed the rate stated on the label. Use of rates lower than the full label rates are carried out at the growers' risk.**

**In some situations, and in some seasons, dryland sites may be more equivalent to irrigated sites. In all situations, monitor rainfall between GS 30 and 39-49 (early stem elongation – awn emergence). For dryland crops where rainfall is well above average, consider irrigated strategies as well as dryland options.**

# An integrated pest management strategy for wheat

Since 2020, FAR's Cereal Disease Management Strategies have focused on an integrated pest management (IPM) approach for control of diseases in wheat. This approach uses cultivar selection and cultural control methods alongside chemistry (Figure 1). It allows growers to exploit the "sweet spot" between disease control and disease management without compromising yield or economic return. It also helps to steward at-risk chemistries such as triazoles (Group 3) and SDHIs (Group 7), along with newer active ingredients such as quinone inside inhibitors (QiIs – Group 21).

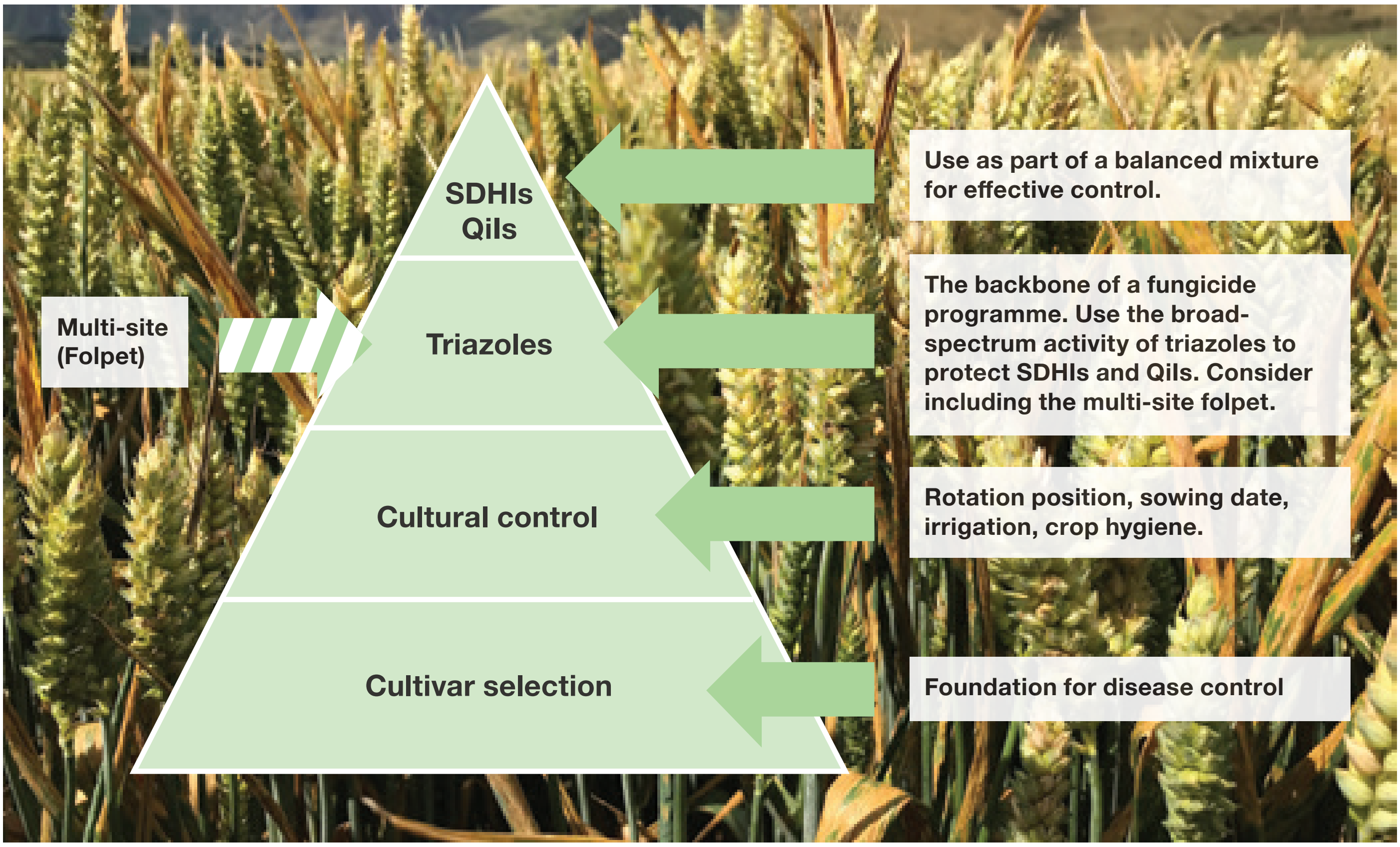


**Figure 8.** An IPM approach to manage Septoria tritici blotch in wheat. Adapted from Integrated Pest Management ahdb.org.uk/cereal_dmg

## A Lighter Touch

Much of FAR's cereal disease management programme is aligned with A Lighter Touch, a seven-year, cross sector MPI SFFF programme, led by Horticulture New Zealand. A Lighter Touch has a focus on agroecology and aims to take IPM to the next level by placing the spotlight on the crop itself. It aims to capture all the good things we know about diversity within a farm system to strategically adjust inputs with the goal of making farm systems more resilient. A key goal is evaluating ways to prolong the effective lives of both chemistries and cultivars. FAR's A Lighter Touch programme fits into three broad, interconnected pillars.

A LIGHTER TOUCH

1. **Effective use of plant genetics:** development of disease management tactics based on cultivar selection and novel strategies to support cultivar stewardship.
2. **Integrating new crop protection technologies:** identification and evaluation of biological products that have potential for use in arable production systems and their incorporation into disease management programmes.
3. **Rationalising chemical pesticide programmes:** development of balanced fungicide programmes that have greater profitability and a reduced environmental footprint, and which support the uptake of IPM practices and resistance management.

# Effective use of plant genetics

## Cultivar resistance, a changing landscape

Cultivar selection and the use of host resistance are the heart of IPM. Host resistance suppresses pathogen build-up and impacts on the way disease shows up in the crop. Informed cultivar selection can provide opportunities to reduce agrichemical use, rotate chemistry and increase flexibility in the timing of sprays or other interventions; saving time and money while taking pressure off the system.

To make the most of host resistance you need up-to-date knowledge of how cultivars are performing against pathogens in the field. This is particularly important for *Zt* (the pathogen responsible for STB) which is highly diverse and highly adaptable. *Puccinia tritici*, the pathogen responsible for leaf rust, is also highly diverse and recent seasons have seen changes to cultivar resistance ratings in cultivar performance trials (CPT) (Figure 1, Table 1).

Pathogens like *Zt* and *P. tritici* are made up of many different pathotypes. Pathotypes are groups of organisms from the same species that cause disease in the same host (in this case, wheat cultivars). Pathotypes can evolve readily, depending on what cultivars are grown and the resulting selection pressure on them. The more the cultivar is grown over a long period of time, the greater its exposure to the pathogen and the greater the likelihood the pathogen will overcome a cultivar's resistance. Similarly, repeated use of the same active ingredient or chemical mode-of-action group against a pathogen, can drive pathogen resistance to that chemistry.

As the pathogen responds to the cultivars of the day, cultivar resistance (and therefore resistance ratings) can change, resulting in what we often call "cultivar breakdown". The cultivar itself stays the same, and the change in performance occurs because the pathogen modifies itself to overcome the cultivar's resistance (Figure 2, Table 1).

**Table 3.** Changes in disease ratings for different wheat cultivars in eighteen irrigated CPT trials at Chertsey, Methven and Temuka from 2018-19 to 2023-24.

| | STB Rating | | Leaf Rust Rating | |
|---|---|---|---|---|
| **Cultivar** | **2018-19** | **2023-24** | **2018-19** | **2023-24** |
| Firelight | MRR | MR | MRR | MSS |
| Graham | MR | MRMS | MRMS | MSS |
| Ignite | MR | MS | MS | MS |
| Kerrin[1] | MRR[1] | MS | MRR[1] | MRMS |
| Reflection | MR | MRMS | MR | MR |
| Starfire | MRMS | MS | MS | MS |
| Voltron | MR | MS | MRMS | MS |
| Wakanui[2] | MRMS | MS[2] | MS | MS[2] |
| Whopper[3] | MSMS[3] | MRMS | MSS[3] | S |

[1] Kerrin: Rating is from 2019-20; [2] Wakanui: Rating is from 2022-23; [3] Whopper: Rating is from 2019-20.

**Key**
HS = highly susceptible
S = susceptible
MSS = mostly susceptible
MS = moderately susceptible
MRMS = intermediate resistance
MR = moderately resistant
MRR = mostly resistant
R = resistant

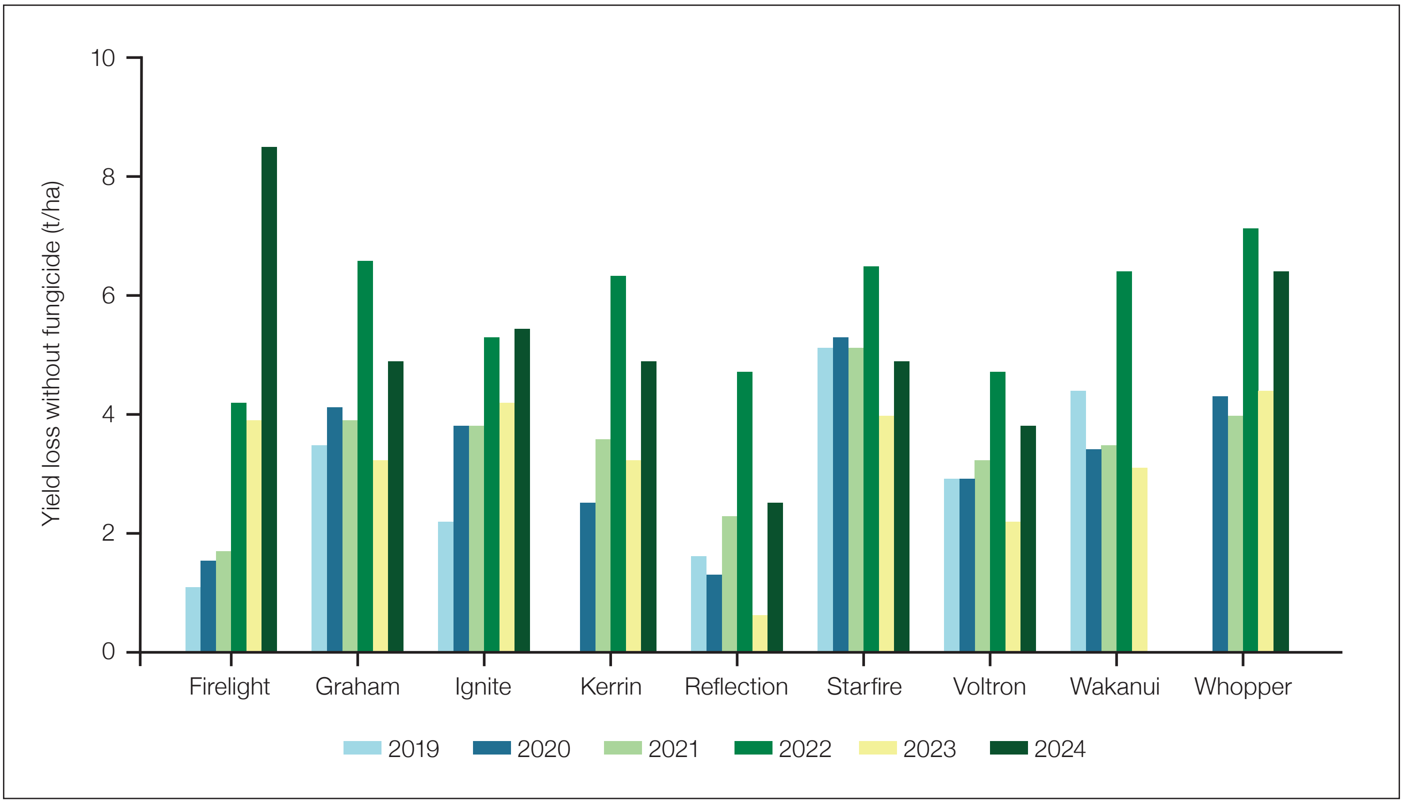


**Figure 2.** Comparative yield responses to fungicide for different wheat cultivars in eighteen irrigated CPT trials at Chertsey, Methven and Temuka from 2018-19 to 2023-24.

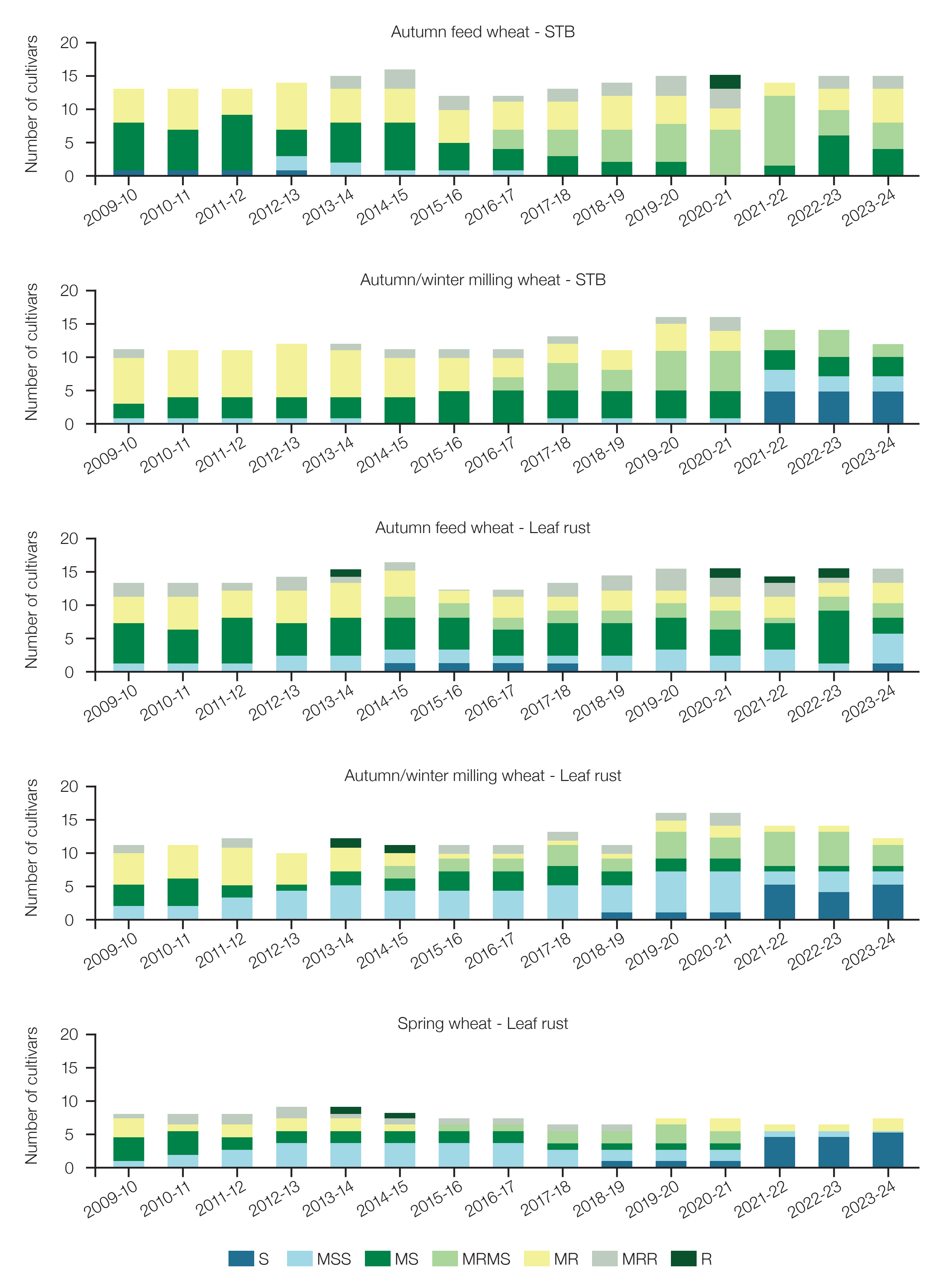


**Figure 3.** Changes in cultivar disease ratings in FAR cultivar performance trials (CPT) since 2009-10. S = Susceptible, MSS = Mostly Susceptible, MS = Moderately Susceptible, MRMS = Moderately Resistant – Moderately Susceptible (Intermediate), MR = Moderately Resistant, MRR = Mostly Resistant, R = Resistant.

Since 2016, irrigated CPT trials at Chertsey, Methven and Temuka have included nil fungicide treatments (Figure 2, Table 1). The relative grain yield losses for different wheat cultivars caused by fungal disease pressure (primarily associated with STB and leaf rust) have been measured in these trials by comparing yields in the nil fungicide treatments with those where fungicides were applied. Over time, this has provided a picture of the cultivars that have been more resilient over the years and when a cultivar breakdown has occurred. The most prominent example of this was 'Firelight', which prior to 2022 was amongst the cultivars that had the lowest yield loss without fungicide and was rated as MRR (mostly resistant) to both STB and leaf rust. The 2022 harvest season was one of the most challenging in recent memory and was preceded by a difficult spring. Many cultivars struggled under high disease pressure, and yield losses without fungicide were high. Under these conditions, a leaf rust pathotype that was particularly virulent on 'Firelight' re-emerged, resulting in yield losses of 4.2 t/ha in 'Firelight' and a leaf rust resistance rating drop from MRR (mostly resistant) in 2024, to MS (moderately susceptible) in 2023 and MSS (mostly susceptible) in 2024.

Cultivar disease resistance rating changes have been monitored in CPT trials over the last 15 years. In this time, the importance of breeding programmes and the introduction of new genetics have been demonstrated by the increased availability of disease resistant feed wheat cultivars, even as older ones are breaking down (Figure 3). However, over the same period of time, milling wheat cultivars have become increasingly more susceptible, likely because breeding and selection has prioritised grain quality. Breeding for grain quality is challenging and time consuming, resulting in lower cultivar turnover; hence many established cultivars have been on the market 10 or more years. This in turn provides greater exposure of cultivar genetics to the pathogens, resulting in the selection of pathotypes that are able to overcome cultivar resistance.

In the absence of disease resistance in milling wheat cultivars, sowing later has become an important way to reduce disease pressure, particularly for *Zt*. Later sowing reduces exposure to airborne inoculum from the sexual phase of the pathogen's lifecycle.

The annual CPT Booklets, available on the FAR website, have further information on the disease profiles for New Zealand cultivars.

## Combining cultivar and fungicide

**Cultivar by fungicide trials emphasise the value of genetics**

Like growers, FAR is always looking to identify the right balance between cultivar selection and fungicide programmes for disease protection. Since 2018, cultivar by fungicide trials have sought to identify specific disease control strategies based on cultivar, infection risk, disease pressure and disease progression. Trials also consider a range of seasons and environments. Emphasis has been placed on understanding the flexibility that cultivar selection can provide around fungicide programme choice and application timings, and the flow on effects on profit and stewarding chemistry.

Data from the 2022-23 and 2023-24 trials has continued to highlight the importance of cultivar selection in disease management. However, changes in cultivar behaviour can catch us out in trials just as easily as they can surprise you on farm. For example, in the 2022-23 season, under contrasting disease pressure (low early, high late), trials with irrigation at Methven in Mid Canterbury and without irrigation at Clinton in South Otago evaluated the cultivars 'Firelight' (MR: STB, MRR: leaf rust), 'Graham' (MRMS: STB, MR: leaf rust) and 'Starfire' (MRMS: STB, MS: leaf rust). For the first time, yield loss without fungicide was not necessarily lower for the more resistant cultivar (Table 2). In this instance, the cultivar rated the most resistant to both STB and leaf rust was 'Firelight'. However, yield loss for 'Firelight' with irrigation in Mid Canterbury was 4.3 t/ha (37%) and 1.7 t/ha (13%) in South Otago (Table 2). In both of these trials, the intermediate cultivar, 'Reflection' proved to be more resilient; yield loss without fungicide was 1.7 t/ha (16%) with irrigation at Methven and 1.2 t/ha (10%) without irrigation in Clinton (Table 2). 'Starfire' suffered yield loss without fungicide of 4.3 t/ha (39%) and 3.2 t/ha (32%) at Methven and Clinton, respectively. Later assessment in Canterbury confirmed 'Firelight' had suffered as a result of changes in the leaf rust pathogen population and had behaved as a more susceptible cultivar. The population changes that crippled 'Firelight' in Canterbury, did not have the same effect on 'Firelight' in South Otago. This suggested there were regional differences in the *P. tritici* pathogen population and highlighted that cultivars may perform differently from one season to another.

We can assign a monetary value to the observed yield losses. These were more pronounced in 2022-23, when grain prices were at record highs. For the most resilient cultivar 'Reflection', yield loss represented revenue losses of $1037/ha with irrigation at Methven and $732/ha without irrigation at Clinton, compared with $2623/ha for both 'Firelight' and 'Starfire' at Methven and $1037/ha and $1952/ha at Clinton, respectively (Table 2).

Subsequent changes in cultivar ratings resulted in different cultivar choices in the 2023-24 cultivar by fungicide trials. 'SY Defiant' (MRR: STB, MRR: leaf rust), was selected as the resistant cultivar, 'Voltron' (MS: STB, MRR: leaf rust) as the intermediate and 'Starfire' (MS: STB, MSS: leaf rust) as the susceptible. Low-moderate disease pressure conditions in 2023-24 saw cultivars behaving to type i.e. yield loss without fungicide was lower for the more resistant cultivar (1.8 t/ha (14%) 'SY Defiant' than for 'Voltron' (3.1 t/ha (25%)) and 'Starfire' (5.7 t/ha (45%)), respectively (Table 3). The associated revenue losses were up to $810/ha for 'SY Defiant', $1413/ha for 'Voltron' and $2574/ha for 'Starfire'.

**Table 2.** Average yield and revenue losses in autumn sown wheat crops without fungicide in FAR 'cultivar x fungicide' programme trials in the 2022-23 season.

| Cultivar (resistance rating) | Methven (irrigated) | | Clinton (dryland) | |
|---|---|---|---|---|
| | Yield loss (t/ha) | Revenue loss ($/ha) | Yield loss (t/ha) | Revenue loss ($/ha) |
| Firelight (MR: STB, MRR: Leaf rust) | 4.3 | 2623 | 1.7 | 1037 |
| Reflection (MRMS: STB, MR: Leaf rust) | 1.7 | 1037 | 1.2 | 732 |
| Starfire (MRMS: STB, MS: Leaf rust) | 4.3 | 2623 | 3.2 | 1952 |

Wheat price: $610/ha, NZ Grain and Feed Insight.

**Table 3.** Average yield and revenue losses in wheat crops without fungicide in FAR 'cultivar x fungicide' programme trials in the 2023-24 season.

| Cultivar (resistance rating) | Methven (irrigated) | |
|---|---|---|
| | Yield loss (t/ha) | Revenue loss ($/ha) |
| SY Defiant (MRR: STB, MRR: Leaf rust) | 1.8 | 450 |
| Voltron (MS: STB, MRR: Leaf rust) | 3.1 | 1413 |
| Starfire (MS: STB, MSS: Leaf rust) | 5.7 | 2574 |

Wheat price: $450/ha, NZ Grain and Feed Insight.

**The sweet spot for fungicide spend depends on both cultivar and season**

High input fungicide programmes undeniably result in clean crops and high yields. However, they do not always provide overall balance from an economic, environmental and stewardship perspective.

The most cost-efficient fungicide programme is one that meets the needs of your chosen cultivar in the current season. Last year's programme won't work if this year's weather patterns have been different or if there has been a shift in the resistance rating of your chosen cultivar; so, select a resistant cultivar and manage it according to the season.

FAR determines the value of cultivar resistance in any one season by calculating the economic returns in cultivar by fungicide trials (revenue minus fungicide cost). This allows the financial outcomes of using a particular cultivar to be measured at different locations. With the exception of 'Firelight' in 2022-23, all FAR trials since 2020-21 have demonstrated that using a more resistant cultivar results in greater yield and profit in unsprayed controls; in other words, the more resistant the cultivar, the lower the return-on-investment from any fungicide and the greater the likelihood of a fungicide overspend. Such inefficiencies can also occur when using a more susceptible cultivar under high disease pressure. For example, in 2022-23, FAR trials comparing two-, three- and four-spray programmes on cultivars with contrasting disease ratings in Canterbury (with irrigation) and South Otago (without irrigation), showed that three-spray programmes including a T1, T2 and T3 provided the best balance between disease, yield and economic returns, regardless of cultivar disease rating (even in a cultivar like 'Starfire').

However, FAR trials have also showed that, depending on the season and the cultivar, you can underspend on fungicide. For instance, in 2023-24, under moderate disease pressure and with irrigation at Methven, the bulk of disease control, yield and profitability was linked to the T1 and T2 applications (Tables 8-9). T0 and T3 applications did not provide additional disease control in 'SY Defiant' and 'Voltron', but a T3 was required for 'Starfire'.

In the same set of trials, while four-spray programmes resulted in high yields for all cultivars, a number of three-spray programmes were more profitable for 'SY Defiant' and 'Starfire'. In contrast, a three-spray programme would have been an underspend for 'Voltron' which required all four treatments to be profitable. This is only the second example since 2016-17 of a response to a T0 application in FAR trials.

These examples highlight the challenges involved in choosing a fungicide programme. The best approach is to use the T1 and T2 as the backbone of the programme, with other applications considered on a seasonal or situational basis.

**Cultivar choice allows timing flexibility**

Cultivar choice can also provide flexibility in your fungicide application timings. For instance, at Methven with irrigation in 2022-23, all cultivars, regardless of disease rating, provided some flexibility if T2 or both T1 and T2 fungicide applications were late (Tables 4 and 5). Flexibility in application timings was less clear-cut in 2023-24 at Methven (Tables 8-9), suggesting seasonal disease pressure conditions are important to consider when timing might be compromised, even when growing a tolerant cultivar. Another example is the case without irrigation at Clinton, where yield, but not necessarily profitability was compromised for 'Starfire' when T2 or T1 and T2 applications were late (Tables 6-7).

It is important to note that depending on disease levels within the crop, delays to applications may place additional pressure on fungicides by shifting their action from preventative to curative. This can increase the risk of resistance development so, regardless of cultivar, pay attention to conditions (such as high rainfall and relative humidity between GS 30 – 59 (roughly late-September to late-November) and try to get fungicides at the optimal time.

**Table 4.** Percent leaf area affected by STB and leaf rust for autumn sown wheat cultivars with different disease ratings, with irrigation at Methven, Mid Canterbury in 2022-23, following application of different fungicide programmes. Disease assessed on the flag leaf - Leaf 4 - at GS 75 + 21 days on January 16, 2023.

| Cultivar | Growth stage (GS), application date and fungicide treatment (L/ha) | | | | | | % LAA[1] by STB | % LAA[1] by Leaf Rust |
|---|---|---|---|---|---|---|---|---|
| | 28.9.22 GS 30-31 | 14.10.22 GS 32 | 25.10.22 GS 33-37 | 9.11.22 GS 39 | 16.11.22 GS 45 | 1.12.22 GS 65 | | |
| Firelight | Untreated | - | - | - | - | - | 60.8 (51.3; 70.2) | 14.2 (9,4; 19.0) |
| Firelight | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 4.6 (0; 14.1) | 1.5 (0; 6.3) |
| Firelight | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 6.9 (0; 16.3) | 0 (0; 4.8) |
| Firelight | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 6.8 (0; 16.3) | 0 (0; 4.8) |
| Firelight | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 6.4 (0; 15.9) | 0 (0; 4.8) |
| Firelight | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 6.5 (0; 16.0) | 0.1 (0; 4.9) |
| Reflection | Untreated | - | - | - | - | - | 17.5 (8.0; 26.9) | 0.1 (0; 4.9) |
| Reflection | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 7.2 (0; 16.6) | 0 (0; 4.8) |
| Reflection | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 6.3 (0; 15.7) | 0 (0; 4.8) |
| Reflection | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 5.2 (0; 14.7) | 0 (0; 4.8) |
| Reflection | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 7.1 (0; 16.6) | 0 (0; 4.8) |
| Reflection | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 3.8 (0; 13.2) | 0 (0; 4.8) |
| Starfire | Untreated | - | - | - | - | - | 80.6 (71.1; 90.0) | 3.1 (0; 7.9) |
| Starfire | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 21.8 (12.3; 26.5) | 0.2 (0; 5.0) |
| Starfire | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 17.0 (7.5; 26.5) | 0 (0; 4.8) |
| Starfire | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 24.9 (15.4; 34.3) | 0 (0; 4.8) |
| Starfire | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 17.8 (8.3; 27.2) | 0 (0; 4.8) |
| Starfire | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 15.7 (6.2; 25.1) | 0.1 (0; 4.9) |
| | | | | | | **Mean** | **17.6** | |
| | | | | | | **P value** | | |
| | | | | | | **Cultivar** | **<0.001** | **0.024** |
| | | | | | | **Fungicide** | **<0.001** | **<0.001** |
| | | | | | | **Cultivar x fungicide** | **<0.001** | **0.004** |

Note: Yellow indicates the treatments that were amongst those that achieved the highest disease control for each cultivar. Differences between treatment means are expressed as 95% upper and lower confidence intervals. Active ingredients: Elatus™ Plus (a.i. 100 g/L benzovindiflupyr – SOLATENOLTM, Group 7 fungicide); Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 fungicide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicide). [1] LAA – leaf area affected by STB or leaf rust. Disease ratings: 'Firelight': STB: moderately resistant (MR), Leaf Rust: mostly resistant (MRR); 'Reflection': STB: moderately resistant-moderately susceptible (intermediate) (MRMS), Leaf Rust: moderately resistant (MR); 'Starfire': STB: moderately resistant-moderately susceptible (MRMS), Leaf Rust: moderately susceptible (MS).

**Table 5.** Yield and Revenue minus fungicide cost for autumn sown wheat cultivars with different disease ratings, with irrigation at Methven, Mid Canterbury in 2022-23, following application of different fungicide programmes. Wheat price $610/t (Source NZ Grain & Feed Insight).

| Cultivar | Growth Stage (GS), application date and fungicide treatment (L/ha) | | | | | | Yield (t/ha) | Revenue – Fung. cost ($/ha) |
|---|---|---|---|---|---|---|---|---|
| | 28.9.22 GS 30-31 | 14.10.22 GS 32 | 25.10.22 GS 33-37 | 9.11.22 GS 39 | 16.11.22 GS 45 | 1.12.22 GS 65 | | |
| Firelight | Untreated | - | - | - | - | - | 7.33 | 4472 |
| Firelight | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 10.98 | 6471 |
| Firelight | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 11.81 | 6898 |
| Firelight | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 11.78 | 6880 |
| Firelight | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 11.87 | 6938 |
| Firelight | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 11.77 | 6818 |
| Reflection | Untreated | - | - | - | - | - | 9.98 | 6087 |
| Reflection | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 11.23 | 6621 |
| Reflection | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 11.62 | 6787 |
| Reflection | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 11.79 | 6885 |
| Reflection | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 11.53 | 6731 |
| Reflection | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 11.67 | 6756 |
| Starfire | Untreated | - | - | - | - | - | 6.77 | 4127 |
| Starfire | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 10.55 | 6208 |
| Starfire | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 11.18 | 6513 |
| Starfire | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 11.26 | 6563 |
| Starfire | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 11.38 | 6636 |
| Starfire | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 11.14 | 6435 |
| | | | | | | **Mean** | **10.87** | **6379** |
| | | | | | | **P value** | | |
| | | | | | | **Cultivar** | **<0.001** | **<0.001** |
| | | | | | | **Fungicide** | **<0.001** | **<0.001** |
| | | | | | | **Cultivar x Fungicide** | **<0.001** | **<0.001** |
| | | | | | | **LSD (p=0.05)** | | |
| | | | | | | **Cultivar** | **0.47** | **285** |
| | | | | | | **Fungicide** | **0.47** | **286** |
| | | | | | | **Cultivar x Fungicide** | **0.46** | **285** |
| | | | | | | **CV (%)** | **2.97** | |

Note: Yellow indicates the treatments that were amongst those that produced the highest grain yield and/or revenue minus fungicide cost for each cultivar. Active ingredients: Elatus™ Plus (a.i. 100 g/L benzovindiflupyr – SOLATENOL™, Group 7 fungicide); Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 fungicide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicideDisease ratings: 'Firelight': STB: moderately resistant (MR), Leaf Rust: mostly resistant (MRR); 'Reflection': STB: moderately resistant-moderately susceptible (intermediate) (MRMS), Leaf Rust: moderately resistant (MR); 'Starfire': STB: moderately resistant-moderately susceptible (MRMS), Leaf Rust: moderately susceptible (MS).

**Table 6.** Percent leaf area affected by STB and leaf rust for autumn sown wheat cultivars with different disease ratings under dryland conditions at Clinton, South Otago in 2022-23, following application of different fungicide programmes. Disease assessed on the flag leaf - Leaf 3 - at GS 75-80 on December 29, 2022.

| Cultivar | Growth stage (GS) and fungicide treatment (L/ha) | | | | | | % LAA[1] by STB | Lower C.L. | Upper C.L. |
|---|---|---|---|---|---|---|---|---|---|
| | GS 30-31 | GS 32 | GS 33-37 | GS 39 | GS 45 | GS 65 | | | |
| Firelight | Untreated | - | - | - | - | - | 71.4 | 55.9 | 91.2 |
| Firelight | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 29.0 | 22.8 | 36.8 |
| Firelight | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 23.8 | 18.8 | 30.2 |
| Firelight | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 22.6 | 17.9 | 28.7 |
| Firelight | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 22.5 | 17.8 | 28.5 |
| Firelight | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 23.4 | 18.5 | 29.7 |
| Reflection | Untreated | - | - | - | - | - | 62.7 | 49.1 | 80.0 |
| Reflection | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 34.9 | 27.5 | 44.5 |
| Reflection | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 28.0 | 22.1 | 35.6 |
| Reflection | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 39.2 | 30.9 | 50.0 |
| Reflection | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 37.4 | 29.4 | 47.7 |
| Reflection | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 25.8 | 20.4 | 32.8 |
| Starfire | Untreated | - | - | - | - | - | 100 | 79.8 | 100 |
| Starfire | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 70.3 | 55.1 | 89.8 |
| Starfire | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 61.5 | 48.2 | 78.5 |
| Starfire | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 64.4 | 50.5 | 82.2 |
| Starfire | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 66.0 | 51.7 | 84.2 |
| Starfire | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 52.9 | 41.5 | 67.5 |
| | | | | | | **Mean** | **46.5** | | |
| | | | | | | **P value** | | | |
| | | | | | | **Cultivar** | <0.001 | | |
| | | | | | | **Fungicide** | <0.001 | | |
| | | | | | | **Cultivar x Fungicide** | 0.001 | | |
| | | | | | | **SE** | | | |
| | | | | | | **Cultivar** | 0.1 | | |
| | | | | | | **Fungicide** | 0.1 | | |
| | | | | | | **Cultivar x Fungicide** | 0.1 | | |

Note: Yellow indicates the treatments that were amongst those that achieved the highest disease control for each cultivar. C.I., differences between treatment means are expressed as 95% upper and lower confidence intervals (C.I.). Active ingredients: Elatus™ Plus (a.i. 100 g/L benzovindiflupyr – SOLATENOL™, Group 7 fungicide); Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 fungicide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicide). [1] LAA – leaf area affected by STB or leaf rust. Disease ratings: 'Firelight': STB: moderately resistant (MR), Leaf Rust: mostly resistant (MRR); 'Reflection': STB: moderately resistant-moderately susceptible (MRMS), Leaf Rust: moderately resistant (MR); 'Starfire': STB: moderately resistant-moderately susceptible (MRMS), Leaf Rust: moderately susceptible (MS).

**Table 7.** Yield and Revenue-minus-fungicide cost for autumn sown wheat cultivars with different disease ratings, under dryland conditions at Clinton, South Otago in 2022-23, following application of different fungicide programmes. Wheat price $560/t (Source NZ Grain & Feed Insight).

| Cultivar | Growth stage (GS) and fungicide treatment (L/ha) | | | | | | Yield (t/ha) | Revenue - Fung. cost ($/ha) |
|---|---|---|---|---|---|---|---|---|
| | GS 30-31 | GS 32 | GS 33-37 | GS 39 | GS 45 | GS 65 | | |
| Firelight | Untreated | - | - | - | - | - | 10.73 | 6003 |
| Firelight | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 12.22 | 6589 |
| Firelight | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 12.46 | 6671 |
| Firelight | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 12.43 | 6651 |
| Firelight | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 12.48 | 6653 |
| Firelight | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 12.30 | 6531 |
| Reflection | Untreated | - | - | - | - | - | 10.16 | 5684 |
| Reflection | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 11.21 | 6028 |
| Reflection | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 11.41 | 6021 |
| Reflection | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 11.45 | 6089 |
| Reflection | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 11.36 | 6018 |
| Reflection | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 11.17 | 5852 |
| Starfire | Untreated | - | - | - | - | - | 6.68 | 3735 |
| Starfire | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 9.38 | 5020 |
| Starfire | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 10.01 | 5292 |
| Starfire | - | Kestrel® (1.0) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 9.76 | 5123 |
| Starfire | - | - | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 9.69 | 5112 |
| Starfire | Opus® (1.0) | Kestrel® (1.0) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | Prosaro® (1.0) | 10.30 | 5392 |
| | | | | | | **Mean** | **10.86** | **5805** |
| | | | | | | **P value** | | |
| | | | | | | **Cultivar** | **<0.001** | **<0.001** |
| | | | | | | **Fungicide** | **<0.001** | **<0.001** |
| | | | | | | **Cultivar x fungicide** | **<0.001** | **<0.001** |
| | | | | | | **LSD (P=0.05)** | | |
| | | | | | | **Cultivar** | **0.21** | **119** |
| | | | | | | **Fungicide** | **0.29** | **161** |
| | | | | | | **Cultivar x fungicide** | **0.50** | **281** |
| | | | | | | **CV (%)** | **2.98** | **-** |

Note: Yellow indicates the treatments that were amongst those that produced the highest grain yield and/or revenus minus fungicide cost for each cultivar. Active ingredients: Elatus™ Plus (a.i. 100 g/L benzovindiflupyr – SOLATENOL™, Group 7 fungicide); Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 fungicide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicide. Disease ratings: 'Firelight': STB: moderately resistant (MR), Leaf Rust: mostly resistant (MRR); 'Reflection': STB: moderately resistant-moderately susceptible (MRMS), Leaf Rust: moderately resistant (MR); 'Starfire': STB: moderately resistant-moderately susceptible (MRMS), Leaf Rust: moderately susceptible (MS).

**Table 8.** Percent leaf area affected by STB and leaf rust for autumn sown wheat cultivars with different disease ratings with irrigation at Methven, Mid Canterbury in 2023-24, following application of different fungicide programmes. Disease assessed on the flag leaf – leaf 3 on at GS 80-85 on January 10, 2024.

| Cultivar | Growth stage (GS) and fungicide treatment (L/ha) | | | | | | % LAA[1] by STB | Lower C.L. | Upper C.L. |
|---|---|---|---|---|---|---|---|---|---|
| | GS 30-31 | GS 32 | GS 33-37 | GS 39 | GS 45 | GS 65 | | | |
| SY Defiant | Untreated | - | - | - | - | - | 11.5 | 6.9 | 16.0 |
| SY Defiant | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | - | 2.7 | 0 | 7.2 |
| SY Defiant | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 2.7 | 0 | 7.2 |
| SY Defiant | - | Kestrel® (1.0) + Phoenix® (1.5) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 3.0 | 0 | 7.5 |
| SY Defiant | - | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 2.3 | 0 | 6.9 |
| SY Defiant | Bolide® (2.0) | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 2.8 | 0 | 7.3 |
| Voltron | Untreated | - | - | - | - | - | 83.0 | 78.5 | 87.6 |
| Voltron | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 6.7 | 2.2 | 11.3 |
| Voltron | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 7.8 | 3.3 | 12.4 |
| Voltron | - | Kestrel® (1.0) + Phoenix® (1.5) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 5.1 | 0.5 | 9.6 |
| Voltron | - | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 5.5 | 1.0 | 10.1 |
| Voltron | Bolide® (2.0) | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 4.0 | 0 | 8.5 |
| Starfire | Untreated | - | - | - | - | - | 100.0 | 95.5 | 100 |
| Starfire | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | - | 24.7 | 20.2 | 29.3 |
| Starfire | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 31.0 | 26.4 | 35.5 |
| Starfire | - | Kestrel® (1.0) + Phoenix® (1.5) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 24.0 | 19.5 | 28.6 |
| Starfire | - | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 20.6 | 16.1 | 25.2 |
| Starfire | Bolide® (2.0) | Kestrel® (1 .0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 17.4 | 12.9 | 22.0 |
| | | | | | | **Mean** | **19.7** | | |
| | | | | | | **P value** | | | |
| | | | | | | **Cultivar** | <0.001 | | |
| | | | | | | **Fungicide** | <0.001 | | |
| | | | | | | **Cultivar x Fungicide** | <0.001 | | |
| | | | | | | **SE** | | | |
| | | | | | | **Cultivar** | 2.1 | | |
| | | | | | | **Fungicide** | 2.1 | | |
| | | | | | | **Cultivar x Fungicide** | 2.3 | | |

Note: Yellow indicates the treatments that were amongst those that achieved the highest disease control for each cultivar. C.I., differences between treatment means are expressed as 95% upper and lower confidence intervals (C.I.). Active ingredients: Bolide® (a.i. 50 g/L epoxiconazole and 225 g/l procloraz, Group 3 fungicide); Elatus™ Plus (a.i. 100 g/L benzovindiflupyr – SOLATENOL™, Group 7 fungicide); Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 fungicide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicide). [1] LAA – leaf area affected by STB or leaf rust. Disease ratings: 'SY Defiant': STB: mostly resistant (MRR), Leaf Rust: mostly resistant (MRR); 'Voltron': STB: moderately susceptible (MS), Leaf Rust: mostly resistant (MRR); 'Starfire': STB: moderately susceptible (MS), Leaf Rust: mostly susceptible (MSS).

**Table 9.** Yield and Revenue-minus-fungicide cost for autumn sown wheat cultivars with different disease ratings, with irrigation at Methven, Mid Canterbury in 2023-24, following application of different fungicide programmes. Wheat price $450/t (Source NZ Grain & Feed Insight).

| Cultivar | Growth stage (GS) and fungicide treatment (L/ha) | | | | | | Yield (t/ha) | Revenue - Fung. cost ($/ha) |
|---|---|---|---|---|---|---|---|---|
| | GS 30-31 | GS 32 | GS 33-37 | GS 39 | GS 45 | GS 65 | | |
| SY Defiant | Untreated | - | - | - | - | - | 11.22 | 5051 |
| SY Defiant | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | - | 12.78 | 5375 |
| SY Defiant | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 12.93 | 5322 |
| SY Defiant | - | Kestrel® (1.0) + Phoenix® (1.5) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 13.01 | 5359 |
| SY Defiant | - | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 12.79 | 5259 |
| SY Defiant | Bolide® (2.0) | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 13.50 | 5486 |
| Voltron | Untreated | - | - | - | - | - | 9.24 | 4156 |
| Voltron | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) | - | - | 12.10 | 5065 |
| Voltron | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 12.40 | 5085 |
| Voltron | - | Kestrel® (1.0) + Phoenix® (1.5) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 12.16 | 4974 |
| Voltron | - | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 12.15 | 4972 |
| Voltron | Bolide® (2.0) | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 12.97 | 5250 |
| Starfire | Untreated | - | - | - | - | - | 6.90 | 3106 |
| Starfire | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | - | 12.09 | 5061 |
| Starfire | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 12.53 | 5141 |
| Starfire | - | Kestrel® (1.0) + Phoenix® (1.5) | - | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 12.70 | 5221 |
| Starfire | - | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 12.85 | 5287 |
| Starfire | Bolide® (2.0) | Kestrel® (1 .0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Opus® (0.75) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 12.89 | 5214 |
| | | | | | | **Mean** | **12.07** | **5021** |
| | | | | | | **P value** | | |
| | | | | | | **Cultivar** | **<0.001** | **<0.001** |
| | | | | | | **Fungicide** | **<0.001** | **<0.001** |
| | | | | | | **Cultivar x fungicide** | **<0.001** | **<0.001** |
| | | | | | | **LSD (P=0.05)** | | |
| | | | | | | **Cultivar** | **0.13** | **57** |
| | | | | | | **Fungicide** | **0.18** | **79** |
| | | | | | | **Cultivar x fungicide** | **0.30** | **133** |
| | | | | | | **CV (%)** | **1.71** | |

Note: Yellow indicates the treatments that were amongst those that achieved the highest yield and/or revenue minus fungicide cost for each cultivar. Active ingredients: Bolide® (a.i. 50 g/L epoxiconazole and 225 g/l procloraz, Group 3 fungicide); Elatus™ Plus (a.i. 100 g/L benzovindiflupyr – SOLATENOL™, Group 7 fungicide); Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 fungicide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicide). [1] LAA – leaf area affected by STB or leaf rust. Disease ratings: 'SY Defiant': STB: mostly resistant (MRR), Leaf Rust: mostly resistant (MRR); 'Voltron': STB: moderately susceptible (MS), Leaf Rust: mostly resistant (MRR); 'Starfire': STB: moderately susceptible (MS), Leaf Rust: mostly susceptible (MSS).

## Can sowing cultivars in mixtures provide disease and yield stability?

**Note: this strategy is not applicable to milling wheat or certified seed growers**

Much like the use of fungicide mode-of action groups, reliance on a single source of genetic resistance to disease, i.e. a single cultivar, is not an effective long-term resistance management strategy. So what other options are available to encourage genetic diversity and reduce the risk of cultivar "breakdown"?

Traditionally, breeding for resistance has relied on a relatively small number of genes providing varying levels of protection and, depending on the gene, at different times in the wheat life cycle (e.g. it is not uncommon for cultivars to have high seedling but low adult resistance). Breeding for traits which are governed by just one gene is much easier than breeding for resistance which encompasses a number of genes, which act cumulatively.

One approach is sowing cultivars in mixtures to create a multi-gene 'obstacle course' to slow down pathogen adaptation. Using cultivar mixtures theoretically reduces disease development in the more susceptible cultivar by creating a dilution effect. At the same time, the more resistant cultivar is buffered against pathogen adaptation due to the diversity of resistance genes employed by the other cultivars in the mixture.

Through the 'A Lighter Touch' programme, FAR has investigated the use of cultivar mixtures or blends. We want to determine their ability to: provide greater stability against changes in pathogen populations, support yield stability via reduced variability in disease response, provide more stable income and steward chemistry by providing opportunities to reduce inputs.

In three years of cultivar mix trials, three cultivars with contrasting disease ratings to STB, and latterly leaf rust, were sown individually and as a three-way mixture of equal parts under irrigated and dryland conditions at Chertsey, Mid Canterbury. Cultivars were selected based on their disease ratings and their complimentary maturity dates. Initial results were promising; disease control and yields conferred by a mixture of 'Firelight' (resistant), 'Graham' (intermediate) and 'Starfire' (susceptible) were between those of 'Firelight' and 'Graham' grown alone. Similar results were achieved with a mixture of 'SY Defiant' (resistant), 'Voltron' (intermediate) and 'Starfire' (susceptible) (Tables 10-13).

One of the challenges of working with diverse and adaptable pathogens is that we don't always have warning as to when pathogen shifts will happen, and whether they will occur over the course of several seasons or much more quickly. The value cultivar mixtures, compared with a single planting of a more tolerant cultivar, is the in-field diversity and dilution they provide.

This theory was well and truly tested in 2022-23, when novel leaf rust pathotypes proved to be highly virulent on the previously tolerant 'Firelight' (Tables 10-11, Figure 4). In this trial, leaf rust reached high levels in untreated monocultures of 'Firelight' (56%) and 'Starfire' (58%). Leaf rust severity was low in 'Reflection' (2%). When sown in a three-way mixture, the genetic diversity of the cultivars was sufficient to reduce disease severity to around 7% across the mix (Tables 10-11, Figure 4).

When three years of cultivar mix trials were consolidated, yield was certainly higher for more tolerant cultivars in both irrigated and dryland trials, but it was also more variable, in part due to the rapid pathogen change that affected 'Firelight' in 2022-23 (Figures 6-5). Yield was also highly variable for the intermediate cultivars, which over three years achieved the same mean yield as the cultivar mixture. Under both irrigated and dryland conditions, the cultivar mixture demonstrated greater yield

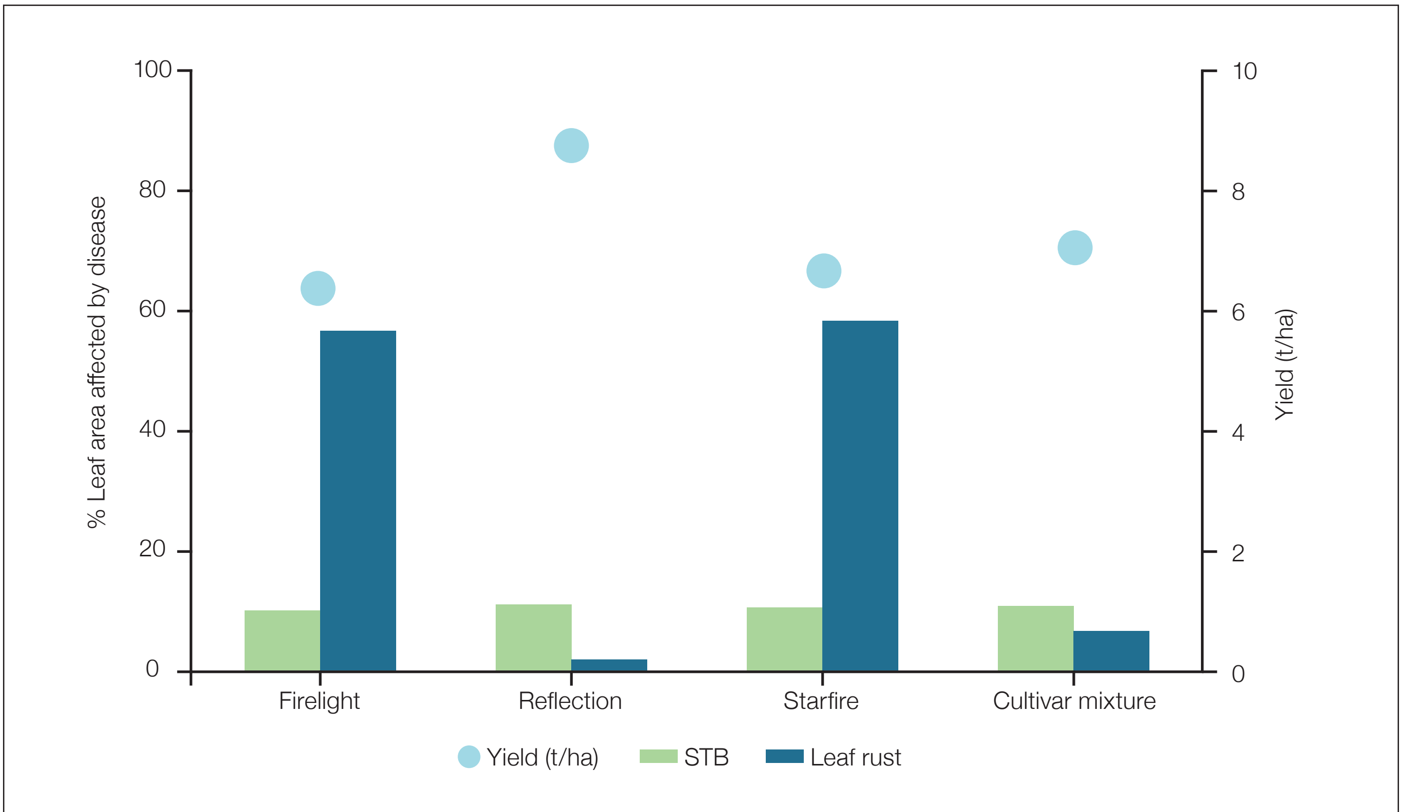


**Figure 4.** Percent leaf area affected by STB and leaf rust and yield of cultivars with different disease ratings sown as monocultures or as a mixture with irrigation at Chertsey, Mid Canterbury in 2022-23.

stability by buffering cultivars against changes in the disease landscape, particularly when pathogen changes were rapid and unexpected. It also provided a means to lift yield over poorer performing susceptible or intermediate cultivars, particularly in higher pressure years. Overall, cultivar mixtures can provide a mechanism to support the performance of more susceptible cultivars and protect more tolerant cultivars from breakdown.

While the theory behind cultivar mixtures is best demonstrated using untreated crops, for cultivar mixtures to be commercially viable it is important to know how they respond to fungicide programmes and whether they can also provide a mechanism to reduce the number of fungicide applications. As in cultivar by fungicide trials, the bulk of disease control, yield and economic returns were associated with fungicide applications at T1 and T2; the T3 could be considered on a seasonal basis. (Tables 10 and 12). Yield response to fungicide without irrigation was comparatively lower than in irrigated trials and was built on the T2 application at GS 39 (Tables 11 and 13). This demonstrated how in yield-limiting environments, the number of applications could be reduced without compromising yield.

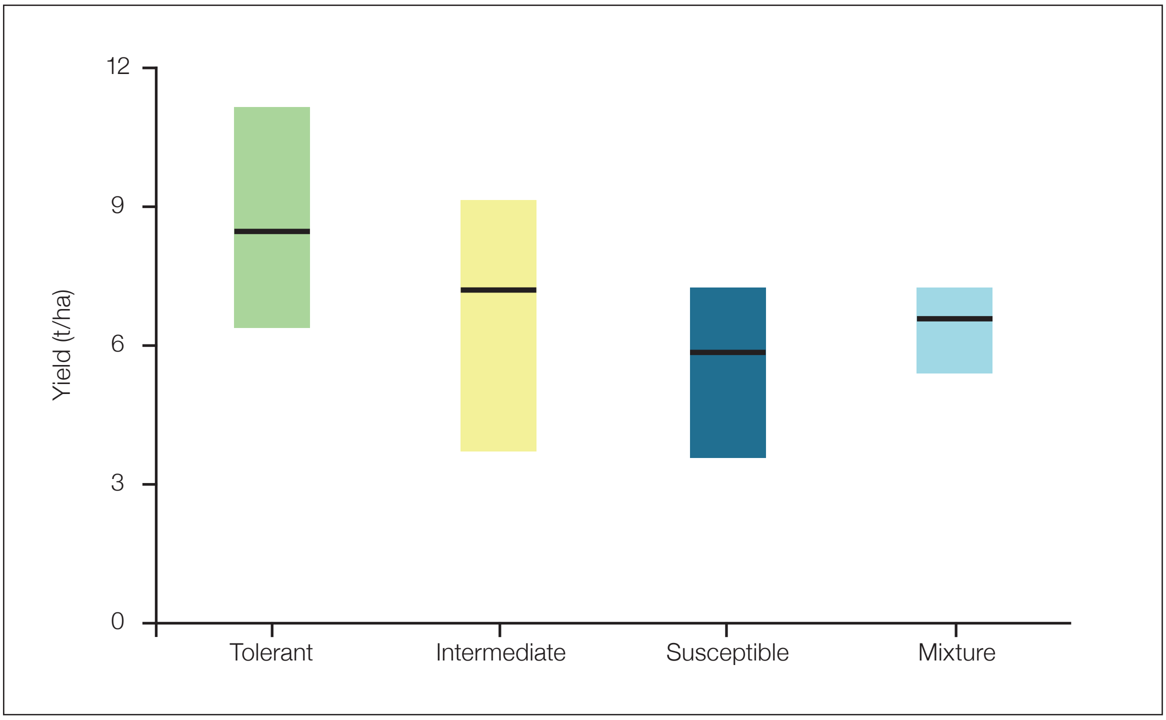


**Figure 5.** Yield of wheat cultivars with contrasting disease ratings sown as monocultures or in a three-way mixture from 2021-22 to 2023-24 at Chertsey, Mid Canterbury with irrigation. Black line represents the mean yield.

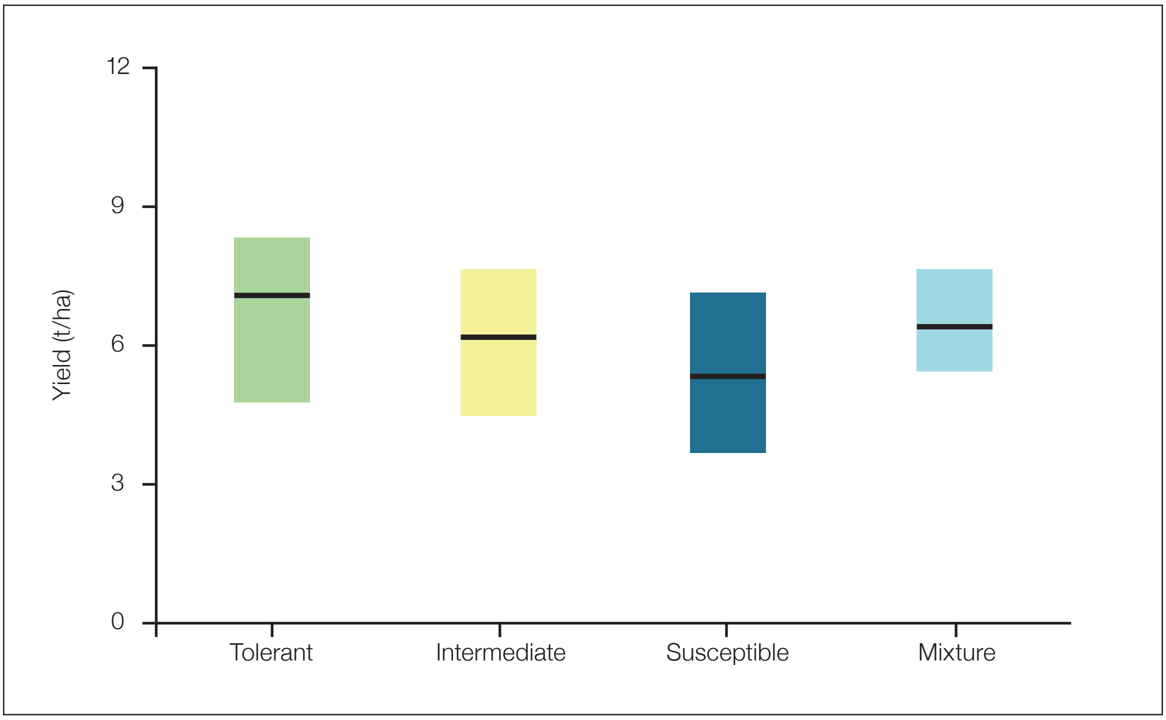


**Figure 6.** Yield of wheat cultivars with contrasting disease ratings sown as monocultures or in a three-way mixture from 2021-22 to 2023-24 at Chertsey, Mid Canterbury without irrigation. Black line represents the mean yield.

Overall, FAR's data suggests that overlaying an appropriate fungicide programme onto cultivar mixtures could be economically viable, improving cultivar and fungicide stewardship by combining a multi-gene 'obstacle course' with different combinations of fungicide modes-of-action.

**Practical considerations for selecting and growing cultivar mixtures**

- Where possible, aim for cultivars that have different parentage to ensure a broad genetic diversity.
- Choose cultivars with similar maturity dates and heights that have good specific weight (kg/hL) and straw strength.
- Home-saved seed from a blend? Be aware that the following crop will not have the same variety ratio to the previous year, and the dominant cultivar may not always be best from one season to another.
- FAR always uses certified seed in cultivar mixtures trials.
- End-users are currently less likely to accept cultivar mixtures for anything other than use as feed, so aim to have a contract in place before drilling.

**Notes on dose rate in dryland environments:** when considering adjustments to dose rate, a reduced rate of a higher risk active ingredient, such as an SDHI (Group 7), which is effective against one disease (e.g. STB), may not provide an appropriate dose to manage another disease (e.g. leaf rust). This sub-lethal dose can increase selection for resistance.

**Table 10.** Percent leaf area affected by STB and leaf rust, yield and margin-over-fungicide cost for autumn sown wheat cultivars with different disease ratings, sown as monocultures or three-way mixtures, with irrigation at Chertsey, Mid Canterbury 2022-23, following application of different fungicide programmes. Disease assessed on the flag leaf - Leaf 3 - at GS 75 on December 20, 2022.

| Cultivar | Growth stage (GS) and fungicide treatment (L/ha) | | | | | | %LAA[1] by STB | % LAA[1] by Leaf Rust | Yield (t/ha) | MoC[2] ($/ha) |
|---|---|---|---|---|---|---|---|---|---|---|
| | GS 30-31 | GS 32 | GS 33-37 | GS 39 | GS 45 | GS 65 | | | | |
| Firelight | Untreated | - | - | - | - | - | 10.37 (7.9; 13.75) | 56.53 (34.78; 92.30) | 6.39 | -447 |
| Reflection | Untreated | - | - | - | - | - | 11.35 (8.61; 15.07 | 2.05 (1.64; 2.73) | 8.75 | 1057 |
| Starfire | Untreated | - | - | - | - | - | 10.45 (7.95; 13.85) | 58 (35.67; 94.71) | 6.65 | -252 |
| Mix | Untreated | - | - | - | - | - | 10.97 (8.34; 14.56) | 6.97 (4.63; 10.81) | 7.07 | * |
| Mix. Fung 1 | | Kestrel® (1.0) | | Elatus™ Plus (0.75) + Opus® (0.75) | | | 6.29 (4.89; 8.19) | 2.1 (1.67; 2.81) | 9.77 | 1463 |
| Mix. Fung 2 | | Kestrel® (1.0) | | | Elatus™ Plus (0.75) + Opus® (0.75) | | 6.66 (5.16; 8.69) | 2.04 (1.63; 2.71) | 9.99 | 1404 |
| Mix. Fung 3 | | - | Kestrel® (1.0) | | Elatus™ Plus (0.75) + Opus® (0.75) | | 5.93 (4.62; 7.70) | 2.04 (1.63; 2.71) | 10.06 | 1625 |
| Mix. Fung 4 | | Kestrel® (1.0) | | Elatus™ Plus (0.75) + Opus® (0.75) | | Prosaro® (1.0) | 4.87 (3.85; 6.26) | 2 (1.61; 2.65) | 10.29 | 1604 |
| Mix. Fung 5 | Opus® (1.0) | Kestrel® (1.0) | | Elatus™ Plus (0.75) + Opus® (0.75) | | Prosaro® (1.0) | 4.26 (3.40; 5.44) | 2 (1.61; 2.65) | 10.54 | 1656 |
| | | | | | | **Mean** | **7.91** | **14.86** | **8.83** | **971** |
| | | | | | | **P value** | **<0.001** | **<0.001** | **<0.001** | **<0.001** |
| | | | | | | **LSD (P=0.05)** | **-** | **-** | **0.76** | **297** |
| | | | | | | **CV (%)** | **-** | **-** | **5.8** | **-** |

Note: Yellow indicates the treatments that were amongst those that had the lowest disease severity, the highest grain yield and/or MoC. Differences between treatment means are expressed as 95% upper and lower confidence intervals. Data was log transformed. Active ingredients: Elatus™ Plus (a.i. 100 g/L benzovindiflupyr – SOLATENOL™, Group 7 fungicide); Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 fungicide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicide). [1] LAA – leaf area affected by STB or leaf rust. Disease ratings in 2022-23: 'Firelight': STB: moderately resistant (MR), Leaf Rust: mostly resistant (MRR); 'Reflection': STB: moderately resistant-moderately susceptible (MRMS), Leaf Rust: moderately resistant (MR); 'Starfire': STB: moderately resistant-moderately susceptible (MRMS), Leaf Rust: moderately susceptible (MS). [2] MoC – margin over fungicide cost Wheat price: $610/t (Source: NZX Grain and Feed Insight.

**Table 11.** Percent leaf area affected by STB and leaf rust, yield and margin-over-fungicide cost for autumn sown wheat cultivars with different disease ratings, sown as monocultures or three-way mixtures, with irrigation at Chertsey, Mid Canterbury 2022-23, following application of different fungicide programmes. Disease assessed on the flag leaf - Leaf 3 - at GS 75 on December 20, 2022.

| Cultivar | Growth stage (GS) and fungicide treatment (L/ha) | | | %LAA[1] by STB | % LAA[1] by Leaf Rust | Yield (t/ha) | MoC[2] ($/ha) |
|---|---|---|---|---|---|---|---|
| | GS 32 | GS 39 | GS 65 | | | | |
| Firelight | Untreated | - | | 12.93 (11.11; 15.08) | 55.76 (44.64; 69.72) | 4.80 | -378 |
| Reflection | Untreated | - | | 11.52 (9.91; 13.41) | 2.0 (1.80; 2.25) | 6.50 | 660 |
| Starfire | Untreated | - | | 12.22 (10.51; 14.25) | 54.79 (43.86; 68.49) | 5.18 | -146 |
| Mix | Untreated | - | | 12.47 (10.72; 14.54) | 22.26 (17.95; 27.68) | 5.46 | * |
| Mix. Fung 1 | - | Elatus™ Plus (0.75) + Opus® (0.75) | | 6.47 (5.64; 7.46) | 2.01 (1.80; 2.26) | 7.34 | 1072 |
| Mix. Fung 2 | - | | | 5.81 (5.08; 6.68) | 2.05 (1.83; 2.31) | 7.83 | 1289 |
| Mix. Fung 3 | Prosaro® (1.0) | | | 5.63 (4.92; 6.47) | 2 (1.80; 2.25) | 7.71 | 1213 |
| Mix. Fung 4 | Kestrel® (1.0) | Elatus™ Plus (0.75) + Opus® (0.75) | | 4.92 (4.32; 5.62 | 2.01 (1.81; 2.27) | 7.47 | 1029 |
| Mix. Fung 5 | Kestrel® (1.0) | Elatus™ Plus (0.75) + Opus® (0.75) | Prosaro® (1.0) | 5.32 (4.66; 6.10) | 2.01 (1.80; 2.27) | 7.87 | 1132 |
| | | | **Mean** | **8.59** | **16.10** | **6.68** | **735** |
| | | | **P value** | **<0.001** | **<0.001** | **<0.001** | **<0.001** |
| | | | **LSD (P=0.05)** | | | **0.59** | **402** |
| | | | **CV (%)** | | | **5.89** | |

Note: Yellow indicates the treatments that were amongst those that had the lowest disease severity, the highest grain yield and/or MoC. Differences between treatment means are expressed as 95% upper and lower confidence intervals. Data was log transformed. Active ingredients: Elatus™ Plus (a.i. 100 g/L benzovindiflupyr – SOLATENOL™, Group 7 fungicide); Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 fungicide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicide). [1] LAA – leaf area affected by STB or leaf rust. Disease ratings in 2022-23: 'Firelight': STB: moderately resistant (MR), Leaf Rust: mostly resistant (MRR); 'Reflection': STB: moderately resistant-moderately susceptible (MRMS), Leaf Rust: moderately resistant (MR); 'Starfire': STB: moderately resistant-moderately susceptible (MRMS), Leaf Rust: moderately susceptible (MS). [2] MoC – margin over fungicide cost Wheat price: $610/t (Source: NZX Grain and Feed Insight.

**Table 12.** Percent leaf area affected by STB and leaf rust for autumn sown wheat cultivars with different disease ratings, sown as monocultures or three-way mixtures, with irrigation at Chertsey, Mid Canterbury 2023-24, following application of different fungicide programmes. Disease assessed on the flag leaf - Leaf 3 - at GS 75 on December 21, 2023. Wheat price $450/t (Source NZ Grain & Feed Insight).

| Cultivar | Growth stage (GS) and fungicide treatment (L/ha) | | | | | | %LAA[1] by STB | % LAA[1] by Leaf Rust | Yield (t/ha) | MoC[2] ($/ha) |
|---|---|---|---|---|---|---|---|---|---|---|
| | GS 30-31 | GS 32 | GS 33-37 | GS 39 | GS 45 | GS 65 | | | | |
| SY Defiant | Untreated | - | - | - | - | - | 8.7 (7.3; 10.3) | 2.1 (1.9; 2.3) | 11.1 (10.6; 11.6) | 903 (706; 1099) |
| Voltron | Untreated | - | - | - | - | - | 12.1 (10.1; 14.4) | 29.2 (24.7; 34.4) | 9.1 (8.7; 9.6) | 44 (-153; 240) |
| Starfire | Untreated | - | - | - | - | - | 15.1 (12.6; 18.0) | 52.1 (44.0; 61.7) | 7.2 (6.7; 7.7) | -848 (-1044; -651) |
| Mix | Untreated | - | - | - | - | - | 15.3 (12.8; 18.3) | 25.4 (21.5; 30.0) | 9.1 (8.6; 9.5) | * |
| Mix. Fung 1 | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Revylution® (1.5) + Phoenix® (1.5) | - | - | 3.6 (3.2; 4.2) | 2.0 (1.9; 2.2) | 12.0 (11.6; 12.5) | 941 (744; 1138) |
| Mix. Fung 2 | - | Kestrel® (1.0) + Phoenix® (1.5) | - | - | Elatus™ Plus (0.75) + Revylution® (1.5) + Phoenix® (1.5) | - | 3.3 (2.9; 3.8) | 2.0 (1.8; 2.2) | 11.8 (11.3; 12.3) | 731 (535; 928) |
| Mix. Fung 3 | - | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Revylution® (1.5) + Phoenix® (1.5) | - | 3.7 (3.2; 4.3) | 2.0 (1.8; 2.1) | 11.9 (11.5; 12.4) | 794 (597; 991) |
| Mix. Fung 4 | - | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Revylution® (1.5) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 2.9 (2.6; 3.3) | 2.0 (1.9; 2.2) | 12.4 (12.0; 12.9) | 1039 (843; 1236) |
| Mix. Fung 5 | Bolide® (1.0) | Kestrel® (1.0) + Phoenix® (1.5) | - | Elatus™ Plus (0.75) + Revylution® (1.5) + Phoenix® (1.5) | - | Opus® (1.0) + Comet® (0.4) | 3.2 (2.8; 3.7) | 2.0 (1.8; 2.2) | 12.2 (11.7; 12.6) | 834 (637; 1030) |
| | | | | | | **Mean** | **7.5** | **13.2** | **10.8** | **555** |
| | | | | | | **P value** | **<0.001** | **<0.001** | **<0.001** | **<0.001** |
| | | | | | | **LSD (P=0.05)** | **-** | **-** | **0.5** | **208.3** |
| | | | | | | **CV (%)** | **-** | **-** | **3.8** | |

Note: Yellow indicates the treatments that were amongst those that had the lowest disease severity. Differences between treatment means are expressed as 95% upper and lower confidence intervals. Data was back transformed. Active ingredients: Bolide® (a.i. 50 g/L epoxiconazole and 225 g/L procloraz, Group 3 fungicide); Comet® (a.i. 250 g/L pyraclostrobin, Group 11 fungicide); Elatus™ Plus (a.i. 100 g/L benzovindiflupyr – SOLATENOL™, Group 7 fungicide); Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 fungicide); Phoenix® (a.i. 500 g/kg folpet, Group M4 fungicide); Revylution® (a.i. 100 g/L mefentrifluconazole, Group 3 fungicide). 1LAA – leaf area affected by STB or leaf rust. Disease ratings: 'Voltron': STB: moderately susceptible (MS), Leaf Rust: moderately susceptible (MS); 'SYDefiant': STB: mostly resistant (MRR), Leaf Rust: mostly resistant (MRR); 'Starfire': STB: moderately susceptible (MS), Leaf Rust: mostly susceptible (MSS).

**Table 13.** Percent leaf area affected by STB and leaf rust, yield (t/ha) and margin-over-fungicide cost (MoC) for autumn sown wheat cultivars with different disease ratings, sown as monocultures or three-way mixtures, under dryland conditions at Chertsey, Mid-Canterbury in 2023-24, following application of different fungicide programmes. Disease assessed on the flag leaf - Leaf 3 - at GS 75 on December 21, 2023. Wheat price $450/t (Source NZ Grain & Feed Insight).

| Cultivar | Growth stage (GS) and fungicide treatment (L/ha) | | | %LAA[1] by STB | % LAA[1] by Leaf Rust | Yield (t/ha) | MoC[2] ($/ha) |
|---|---|---|---|---|---|---|---|
| | GS 32 | GS 39 | GS 65 | | | | |
| SY Defiant | Untreated | - | | 19.7 (15.1; 25.7) | 2.0 (1.8; 2.2) | 8.1 (7.4; 8.7) | 253 (-35; 541) |
| Voltron | Untreated | - | | 11.0 (8.6; 14.3) | 58.5 (48.1; 71.2) | 7.6 (7.0; 8.2) | 51 (-237; 339) |
| Starfire | Untreated | - | | 10.9 (8.5; 14.0) | 53.2 (43.8; 64.7) | 7.1 (6.5; 7.7) | -172 (-461; 116) |
| Mix | Untreated | - | | 12.8 (9.9; 16.6) | 23.6 (19.5; 28.6) | 7.6 (6.9; 8.2) | * |
| Mix. Fung 1 | - | Elatus™ Plus (0.375) + Revylution® (1.5) + Phoenix® (1.5) | - | 8.9 (6.9; 11.4) | 2.1 (1.9; 2.3) | 8.3 (7.7; 8.9) | 162 (-127; 450) |
| Mix. Fung 2 | - | Elatus™ Plus (0.75) + Revylution® (1.5) + Phoenix® (1.5) | - | 7.6 (6.0; 9.8) | 2.1 (1.9; 2.3) | 8.2 (7.6; 8.8) | 63 (-226; 351) |
| Mix. Fung 3 | Prosaro® (1.0) + Phoenix® (1.5) | Elatus™ Plus (0.375) + Revylution® (1.5) + Phoenix® (1.5) | - | 7.5 (5.9; 9.6) | 2.1 (1.9; 2.3) | 8.6 (8.0; 9.2) | 158 (-131; 446) |
| Mix. Fung 4 | Kestrel® (1.0) + Phoenix® (1.5) | Elatus™ Plus (0.75) + Revylution® (1.5) + Phoenix® (1.5) | - | 10.6 (8.2; 13.6) | 2.1 (1.9; 2.3) | 8.3 (7.6; 8.9) | -62 (-351; 226) |
| Mix. Fung 5 | Kestrel® (1.0) + Phoenix® (1.5) | Elatus™ Plus (0.75) + Revylution® (1.5) + Phoenix® (1.5) | Opus® (1.0) + Comet® (0.4) | 9.5 (7.4; 12.3) | 2.0 (1.8; 2.2) | 8.4 (7.7; 9.0) | -115 (-403; 174) |
| | | | **Mean** | **10.9** | **16.4** | **8.0** | **42.1** |
| | | | **P value** | **<0.001** | **<0.001** | **0.007** | **0.206** |
| | | | **LSD (P=0.05)** | **-** | **-** | **0.6** | **302.7** |
| | | | **CV (%)** | **-** | **-** | **5.6** | |

Note: Yellow indicates the treatments that were amongst those that produced the highest grain yield and/or MoC. Active ingredients: Comet® (a.i. 250 g/L pyraclostrobin, Group 11 fungicide); Elatus™ Plus (a.i. 100 g/L benzovindiflupyr – SOLATENOL™, Group 7 fungicide); Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 fungicide); Phoenix® (a.i. 500 g/kg folpet, Group M4 fungicide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicide); Revylution® (a.i. 100 g/L mefentrifluconazole, Group 3 fungicide).

# Integrating new plant protection technologies: Biologicals

**Key points**

- Biopesticides are not direct substitutes for synthetic chemistry and there are many logistical considerations to ensure their effectiveness.
- Biopesticides can provide a viable alternative to synthetic pesticides at some timings.
- FAR trials in 2022-23 and 2023-24 found that disease management programmes which included both biopesticide and conventional products did not compromise disease control or yield.
- Trial results showed that biopesticides could be used at T3 (GS 59) and sometimes at T1 and T3 (GS 32 and 59) to reduce the number of fungicides in a season.
- A conventional seed treatment and T2 (GS 39) was still required.
- Including biopesticides in a cereal disease management programme can reduce the number of fungicides in a season and help prolong the availability of at-risk active ingredients.

## Considering biopesticides

Biopesticides use living organisms and their derivatives to target specific pests or pathogens. They may work directly or indirectly, by attraction/repellence, competition, physical action, parasitism, toxicity and induced resistance (inducing plant defense mechanisms). They typically have a specific label claim against a pest or pathogen, although many also have claims to support plant health.

Biopesticides are not direct substitutes for synthetic chemistry and there are many logistical considerations to ensure their effectiveness. These include product storage, conditions at application, timing and method of application and whether or not they are compatible with other crop protection products. Ensuring biopesticides reach the right area at the right time, with sufficient density to be effective and keeping them where they need to be are challenging. Furthermore, successful application of biopesticides requires a sound understanding of their biology and mode-of-action, and that of the target pest or pathogen and host crop.

Unlike synthetic pesticides, which offer broad-spectrum control and immediate results, biopesticides, are generally protectants, so will not necessarily deliver the curative knockdown effect seen with most synthetic pesticides. This means they need to be applied before symptoms occur, often at different or more frequent application timings.

## Integrating biopesticides into arable

The most important things to consider here are 'will they work' and 'will they provide an economic benefit'? Most biopesticides have been developed for use on high value horticultural crops and may not make economic sense in arable systems. They also may not have activity against arable pests or pathogens. For example, a biopesticide that controls powdery mildew (part of the *Eryiphaceae* family of fungi) in horticultural crops, is unlikely to have activity against it in cereals and even less chance of dealing with STB in wheat or Ramularia leaf spot (RLS) in barley (both are members of the *Mycosphaerellaceae* family). But that doesn't mean there are not opportunities to use biopesticides in cereals, it means you need to do your homework and ask lots of questions before making decisions.

## Biopesticides and IPM

An IPM approach uses biological, cultural and chemical options to manage pests and diseases in a more profitable and sustainable way, whilst alleviating the pressure on cultivars and pesticides from regulation and resistance.

This IPM approach has formed the basis of recent FAR research to:

1. Identify and test biological alternatives to conventional fungicide and insecticide seed and in-season treatments.
2. Develop and evaluate pest management strategies that integrate use of these biopesticides with commonly used chemistries.

Since 2020-21 FAR has been investigating how biopesticides could fit into an IPM programme in wheat. Based on a three-spray, one SDHI (Group 7) programme, FAR's approach was to identify timings associated with the least amount of risk, then incrementally increase the number of biopesticides in the programme. Starting with seed treatments, various products were screened, and an IPM programme was built around knowledge of the likely pests and pathogens, and their respective pressures throughout the season (Figure 1).

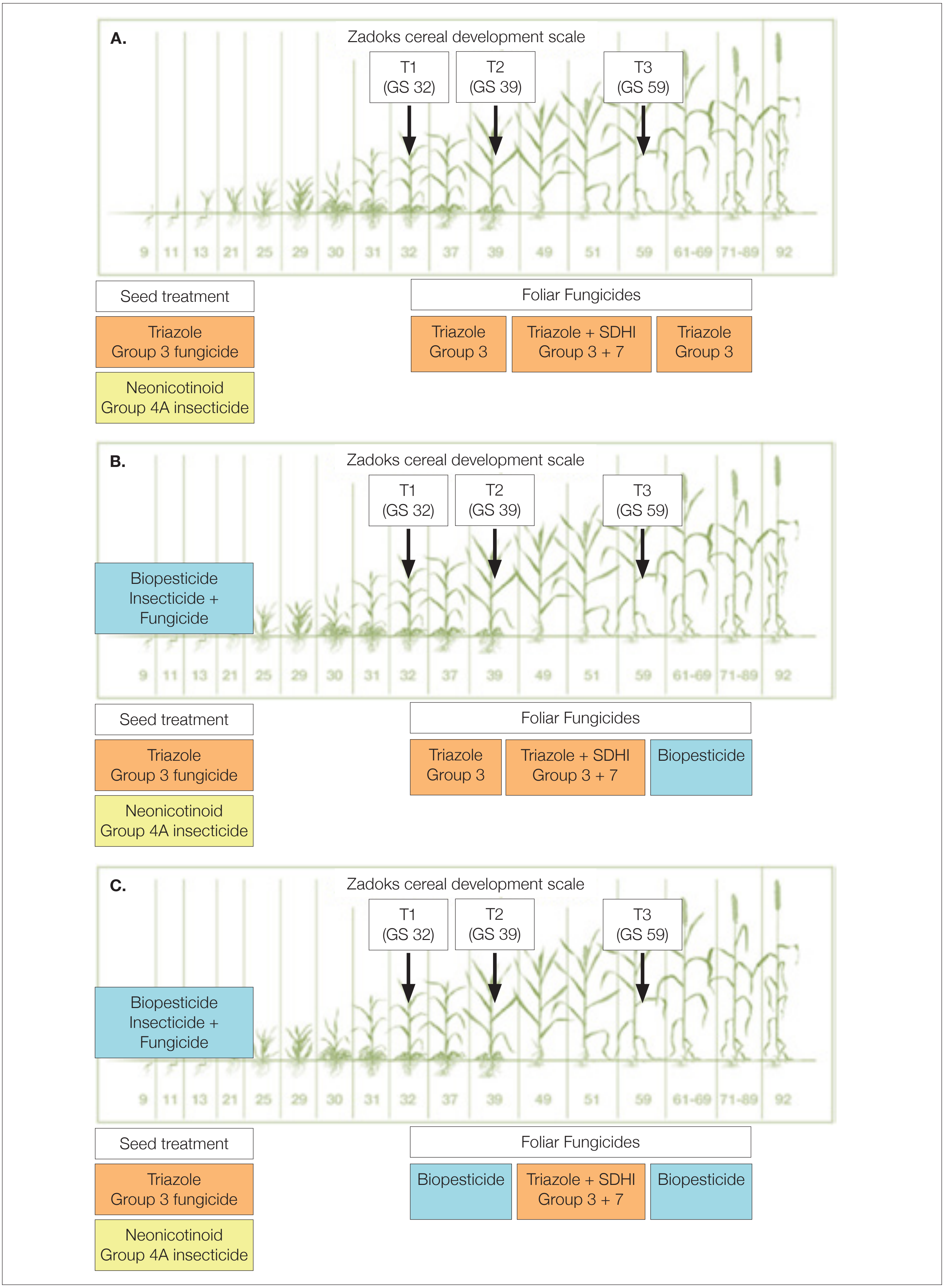


**Figure 1.** Opportunities to integrate biopesticide seed and foliar treatments into wheat disease and pest management programmes. **a.** conventional three-spray, 1-SDHI approach; **b.** two-spray, 1-SDHI, 1-biopesticide ± biopesticide seed treatment; **c.** one-spray, 1-SDHI 2-biopesticids ± biopesticide seed treatment.

## Where to start?

### Seek advice

If you are considering adding biopesticides to your cereal disease management programme, you will need to do some homework first. In 2021, FAR produced a publication General Principles for Good Management Practices – Biopesticides', which outlined how biopesticides work, how to use them and what questions to ask when considering their use. One of the most important considerations is knowing what the product contains, as not all microbes, even those with the same name (e.g. Trichoderma), are created equal and not all are beneficial.

### Try them in a low risk scenario

As biopesticides are unlikely to provide the same level of control as a synthetic option, selecting a cultivar that has at least a moderate level of resistance to both STB and leaf rust will provide the biopesticide with the best chance of success.

FAR cultivar by fungicide and fungicide trials have highlighted the importance of T1 and T2 applications for disease control. Thus, FAR IPM programmes use conventional products at these economically important timings, and suggest integrating biopesticides at less crucial times of the crop's development (Figure 1).

For example, as data suggests that failure to control disease at T3 (GS 59) is less likely to be catastrophic to the crop, use of a biopesticide instead of a synthetic fungicide at this time will provide the highest likelihood of success, especially if the target disease is not STB (Figure 1).

Another potential time to incorporate a biopesticide for the less risk-averse is T1 (GS 32). While it is still considered a 'Priority 1' time, it is of less importance than T2 (GS 39)

### Know the mode-of-action of your biological

It's important to understand the specifics of the biopesticide you intend to use. Make sure you are clear on the genus, species and strain if the product is based on a single microbe, or the product consistency and quality if it contains multiple microbes. FAR has shared the known mode-of-action groups of the products included in trials (Table 1). Many of these products are pre-commercial or have come from horticultural crops and are still being developed for use in the arable sector.

## What does the research say?

### Can biopesticides work in a programme?

In 2022-23, biopesticide trials in crops with and without irrigation, were established at Chertsey, Mid Canterbury using 'Reflection' (a cultivar which is moderately resistant to moderately susceptible (MS) to STB and moderately resistant (MR) to leaf rust). 2023-24 trials, also with and without irrigation at Chertsey, used 'SY Defiant' (mostly resistant (MRR) to both STB and leaf rust). The results from both years demonstrated that strategic use of biopesticides could achieve acceptable levels of disease control and that A Lighter Touch programmes, including a biopesticide, were equally as productive as one based on conventional seed treatments and three foliar fungicides (Tables 1-3).

### Biological seed treatments do not currently have the required efficacy

Combined fungicide and insecticide seed treatments are an economically sound return on investment known to improve plant density, promote growth and increase yield. They are often the first line of defence against pest and pathogen attack for vulnerable early seedlings. In 2022-23, with and without irrigation, crops where biopesticide seed treatments were applied suffered from plant loss at establishment compared with conventionally treated and bare seed (Table 2). This was also true for the irrigated trial in 2023-24 (Table 5). Plants in these treatments were never able to fully compensate for earlier plant losses, affecting yield. In the 2023-24 dryland trial, plant establishment for conventional and biopesticide seed treatments was similar (Table 5). Grass grub pressure in both seasons was low.

Seed treatments were put under the spotlight in 2023-24 trial at Somerton, Mid Canterbury. As in the 2022-23 and 2023-24 biopesticide trials at Chertsey, biopesticide only seed treatments suffered from reduced plant population at establishment (Table 8). This was also true for biopesticide plus biostimulant and biopesticide plus synthetic insecticide treatments. These treatments subsequently suffered from yield loss. The common denominator for treatments that had higher plant populations and ultimately yield, including where biopesticides were used in combination with synthetic options, was use of a synthetic fungicide seed treatment (Table 8).

Relatively little is known about the compatibility of biopesticides used in combination with other biopesticides. Ultimately, their success is dependent on environmental conditions, and on being applied in the right place at the right time. While it is not possible to determine why the performance of the biopesticide seed treatment product combinations were affected, it may have been via competition for space and nutrients, colonization issues or microbe compatibility. This highlights the challenges faced by biopesticides in the field.

FAR will continue with its efforts to explore alternatives to conventional fungicide and insecticide seed treatments, whether these be stand-alone or used strategically alongside one or more synthetic product.

### Foliar biopesticides can facilitate a reduction in synthetic fungicides without compromising disease control of yield.

In 2022-23, despite high late-season disease pressure, control of STB in irrigated and dryland crops of 'Reflection' was not compromised when biopesticides were introduced at T3 (GS 59) or at T1 and T3 (GS 32 and 59), regardless of the preceding seed treatment. This indicated that seed treatment did not have a role in disease control later in the season. (Tables 3-4). Trace levels of leaf rust were observed in these trials. This was also largely true for the 2023-24 trials using 'SY Defiance', where late-season STB pressure was also a feature.

With irrigation, use of biopesticides at T3 (GS 59) or at both T1 and T3 (GS 32 and 59) did not significantly reduce yield compared with a conventional three-spray fungicide programme, provided a conventional fungicide and insecticide seed treatment were used. Yield losses of 7% were observed where a three-spray foliar fungicide programme was preceded by biopesticide seed treatments and up to 18% where biopesticide seed treatments were followed by a three-spray programme that included biopesticides at T1 and T3 (GS 32 and 59). These data suggest that if cultivar disease ratings and seasonal disease pressure are favourable, and a conventional seed treatment is applied, integrating biopesticides at strategic timings may be a viable option. However, the economics of such an approach will depend on the, as yet unknown, prices of biopesticide products.

The intensity of fungicide treatments that can maximise economic returns will vary with seasonal disease pressure and may look different for different cultivars. Ultimately, by prioritising fungicide application timings, particularly those at T1 and T2 timings, there is scope to include biopesticides at less risky times. Any reduction in the number of synthetic pesticide applications not only reduces the chemical footprint of the crop, but reduces the risk of sensitivity shifts to chemistry in pathogen populations. This is significant, because trials in both 2022-23 and 2023-24 highlighted the importance of fungicide seed treatments, which are predominantly based on triazole (Group 3) fungicides. The resistance management guidelines on triazole fungicide labels stipulate that no more than three applications should be used in a season, including a seed treatment. If we have to retain the triazole seed treatment, we will need to look to foliar disease timings for opportunities to reduce the number of triazoles later in the programme. Triazole seed treatments are also under restricted use in some international markets for other reasons. Our biopesticide integration trials have shown where opportunities lie to find solutions to these issues.

FAR will continue to study the possible integration of biopesticides and assess the economic and less tangible returns of biopesticide use for wheat disease management programmes. Biostumulants will also feature in future FAR trials.

**Table 1.** Seed treatment and foliar biopesticides applied to autumn sown wheat cultivar 'Reflection' (2022-23) and 'SY Defiant' (2023-24), with and without irrigation at Chertsey, Mid Canterbury.

| FAR Code | Use | Biological Group | Mode of Action | Details |
|---|---|---|---|---|
| I21-01 BP | Seed treatment – Insecticide | Bacterium – *Serratia spp.* | IRAC* code not known | Insecticidal bacterium; target pest: grass grub |
| F21-02 BP | Seed treatment – Fungicide | Fungus – *Trichoderma spp.* | FRAC* code BM 02 | Biologicals with multiple modes of action: Microbial – fungal; multiple effects including but not exclusive to competition, mycoparasitism, antibiosis, membrane disruption by fungicidal lipopeptides, lytic enzymes, induced plant defense |
| F21-03 BP | Foliar fungicide | Plant extract – terpene hydrocarbons, alcohols, phenols | FRAC* code BM 01 | Biologicals with multiple modes of action: plant extract, cell membrane disruption, cell wall, induced plant defense mechanisms |
| F21-04 BP | Foliar fungicide | Peptide | FRAC* code P(X) | Host plant defense induction; peptide |
| F22-01 BP | Seed treatment and foliar fungicide | Bacterium – *Bacillus spp.* | FRAC* code BM 02 | Biologicals with multiple modes of action: Microbial – bacterium; multiple effects including but not exclusive to competition, parasitism, antibiosis, membrane disruption by fungicidal lipopeptides, lytic enzymes, induced plant defense |
| F22-02 BP | Seed treatment – Fungicide | Fungus – *Trichoderma spp.* | FRAC* code BM 02 | Biologicals with multiple modes of action: Microbial – fungal; multiple effects including but not exclusive to competition, mycoparasitism, antibiosis, membrane disruption by fungicidal lipopeptides, lytic enzymes, induced plant defense |
| F22-03 BP | Seed treatment – Biostimulant | Peptide | N/A | Biostimulant formulated to stimulate root and shoot growth, improve establishment and promote crop development |

*IRAC: Insecticide Resistance Action Committee; *FRAC: Fungicide Resistance Action Committee.

**Table 2.** Final plant population of wheat cultivar 'Reflection' when sown with a target plant population of 150 plants/m$^2$ into a population of 147 New Zealand grass grub larvae/m2 following treatment with conventional and biopesticide seed treatments.

| | | Final Plant Population/m$^2$ | |
|---|---|---|---|
| **Tmt** | **Seed treatment** | **Irrigated** | **Without Irrigation** |
| 1 | Bare seed | 98 | 116 |
| 2 | Rancona® Dimension + Poncho® | 108 | 107 |
| 3 | FAR21-01BP + FAR21-02BP | 74 | 91 |
| | **Mean** | **94** | **105** |
| | **P value** | **<0.001** | **<0.001** |
| | **LSD (P=0.05)** | **10** | **14** |

Note: Yellow indicates the treatments that were amongst those that achieved the highest final plant population. Active ingredients: Poncho® (a.i. 600 g/L clothianidin, Group 4A insecticide); Rancona® Dimension (a.i. 25 g/L ipconazole and 20 g/L metalaxyl, Group 3 and 4 fungicide); FAR21-01BP: Group BM02 fungicide; FAR21-02BP: IRAC insecticide group not specified.

**Table 3.** Percent leaf area affected by STB and grain yield for autumn sown wheat, cultivar Reflection, with irrigation at Chertsey, Mid Canterbury in 2022-23, following application of different fungicide programmes. Disease assessed on the flag leaf - Leaf 3 - at GS 75 days on December 16, 2022.

| Growth stage (GS), application date and fungicide treatment (L/ha) | | | | | % LAA[1] by STB | Lower C.I.[2] | Upper C.I[2] | Yield (t/ha) |
|---|---|---|---|---|---|---|---|---|
| **Tmt no.** | **Seed treatment** | **14.10.22 GS 32** | **7.11.22 GS 39** | **1.12.22 GS 65** | | | | |
| 1 | Bare seed | Nil | Nil | Nil | 61.2 | 44.0 | 72.2 | 8.85 |
| 2 | Rancona® Dimension + Poncho® | Kestrel® (1.0) | Revystar® (1.5) | Prosaro® (1.0) | 26.8 | 18.7 | 30.3 | 10.43 |
| 3 | I21-01 BP + F21-02 BP | Kestrel® (1.0) | Revystar® (1.5) | Prosaro® (1.0) | 21.5 | 15.6 | 25.2 | 9.63 |
| 4 | Rancona® Dimension + Poncho® | Kestrel® (1.0) | Revystar® (1.5) | F21-03 BP | 25.4 | 18.5 | 29.9 | 10.09 |
| 5 | I21-01 BP + F21-02 BP | Kestrel® (1.0) | Revystar® (1.5) | F21-03 BP | 25.2 | 18.3 | 26.3 | 8.56 |
| 6 | Rancona® Dimension + Poncho® | Kestrel® (1.0) | Revystar® (1.5) | F21-04 BP | 21.6 | 15.7 | 25.3 | 10.36 |
| 7 | I21-01 BP + F21-02 BP | Kestrel® (1.0) | Revystar® (1.5) | F21-04 BP | 22.9 | 16.6 | 26.9 | 8.51 |
| 8 | Rancona® Dimension + Poncho® | F21-03 BP | Revystar® (1.5) | F21-03 BP | 28.8 | 20.9 | 33.9 | 10.10 |
| 9 | I21-01 BP + F21-02 BP | F21-03 BP | Revystar® (1.5) | F21-03 BP | 21.6 | 15.7 | 25.3 | 8.76 |
| | | | | **Mean** | **28.2** | | | **9.47** |
| | | | | **P value** | **<0.001** | | | **<0.001** |
| | | | | **LSD (P=0.05)** | **-** | | | **0.67** |
| | | | | **CV (%)** | **-** | | | **5.07** |

Note: Yellow indicates the treatments that were amongst those that achieved the highest disease control. [1] LAA – leaf area affected by STB (differences between treatment means are expressed as 95% upper and lower confidence intervals). [2] C.I.: confidence interval. Active ingredients: Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Poncho® (a.i. 600 g/L clothianidin, Group 4A insecticide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicide); Rancona® Dimension (a.i. 25 g/L ipconazole and 20 g/L metalaxyl, Group 3 and 4 fungicide); Revystar® (a.i. 100 g/L mefenitrifluconazole and 50 g/L fluxapyroxad, Group 3 and 7 fungicide).

**Table 4.** Percent leaf area affected by STB and grain yield for autumn sown wheat, cultivar Reflection, under dryland conditions at Chertsey, Mid Canterbury in 2022-23, following application of different fungicide programmes. Disease assessed on the flag leaf (leaf 3) at GS 75 days on December 16, 2022.

| Growth stage (GS), application date and fungicide treatment (L/ha) | | | | | % LAA[1] by STB | Lower C.I.[2] | Upper C.I[2] | Yield (t/ha) |
|---|---|---|---|---|---|---|---|---|
| **Tmt no.** | **Seed treatment** | **14.10.22 GS 32** | **7.11.22 GS 39** | **1.12.22 GS 65** | | | | |
| 1 | Bare seed | Nil | Nil | Nil | 11.4 | 8.4 | 15.5 | 8.46 |
| 2 | Rancona® Dimension + Poncho® | Kestrel® (1.0) | Revystar® (1.5) | Opus® (0.25) + Amistar® (0.25) | 5.4 | 4.0 | 7.2 | 9.12 |
| 3 | I21-01 BP + F21-02 BP | Kestrel® (1.0) | Revystar® (1.5) | Opus® (0.25) + Amistar® (0.25) | 4.7 | 3.6 | 6.1 | 8.35 |
| 4 | Rancona® Dimension + Poncho® | Kestrel® (1.0) | Revystar® (1.5) | F21-03 BP | 5.1 | 3.9 | 6.7 | 9.10 |
| 5 | I21-01 BP + F21-02 BP | Kestrel® (1.0) | Revystar® (1.5) | F21-03 BP | 4.9 | 3.8 | 6.5 | 8.84 |
| 6 | Rancona® Dimension + Poncho® | Kestrel® (1.0) | Revystar® (1.5) | F21-04 BP | 6.7 | 5.1 | 9.0 | 9.12 |
| 7 | I21-01 BP + F21-02 BP | Kestrel® (1.0) | Revystar® (1.5) | F21-04 BP | 5.6 | 4.3 | 7.5 | 8.83 |
| 8 | Rancona® Dimension + Poncho® | F21-03 BP | Revystar® (1.5) | F21-03 BP | 6.4 | 4.9 | 8.5 | 9.28 |
| 9 | I21-01 BP + F21-02 BP | F21-03 BP | Revystar® (1.5) | F21-03 BP | 5.5 | 4.2 | 7.3 | 8.46 |
| | | | | **Mean** | **6.2** | | | **8.84** |
| | | | | **P value** | **<0.001** | | | **0.061** |
| | | | | **LSD (P=0.05)** | | | | **0.66** |
| | | | | **CV (%)** | | | | **5.02** |

Note: Yellow indicates the treatments that were amongst those that achieved the highest disease control. [1] LAA – leaf area affected by STB (differences between treatment means are expressed as 95% upper and lower confidence intervals). [2] C.I.: confidence interval. Active ingredients: Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Poncho® (a.i. 600 g/L clothianidin, Group 4A insecticide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicide); Rancona® Dimension (a.i. 25 g/L ipconazole and 20 g/L metalaxyl, Group 3 and 4 fungicide); Revystar® (a.i. 100 g/L mefenitrifluconazole and 50 g/L fluxapyroxad, Group 3 and 7 fungicide).

**Table 5.** Final plant population of wheat cultivar 'Reflection' when sown with a target plant population of 150 plants/m$^2$ into a population of 147 New Zealand grass grub larvae/m$^2$ following treatment with conventional and biopesticide seed treatments.

| | | Final Plant Population/m$^2$ | |
|---|---|---|---|
| **Tmt** | **Seed treatment** | **Irrigated** | **Without Irrigation** |
| 1 | Bare seed | 142 | 131 |
| 2 | Poncho® + Suscon® Green + Bioshield® + Rancona® Dimension (Conventional) | 165 | 141 |
| 3 | Bioshield® + F22-01 BP (Biololgical) | 131 | 154 |
| | **Mean** | **145** | **142** |
| | **P value** | **<0.001** | **0.003** |
| | **LSD (P=0.05)** | **10** | **13** |

Note: Yellow indicates the treatments that were amongst those that achieved the highest final plant population. Active ingredients: Poncho® (a.i. 600 g/L clothianidin, Group 4A insecticide); Suscon® Green (a.i. 100 g/L chlorpyrifos, Group 1 insecticide); Rancona® Dimension (a.i. 25 g/L ipconazole and 20 g/L metalaxyl, Group 3 and 4 fungicides); BioShield® (a.i. 4 x 1010 cfu/g *Serratia entomophila*), F22-01 BP: *Bacillus spp*. FRAC code BM 02 fungicide: Biologicals with multiple modes of action.

**Table 6.** Percent leaf area affected by STB and leaf rust for autumn sown wheat, cultivar 'SY Defiant', with irrigation at Chertsey, Mid Canterbury in 2023-24, following application of different fungicide programmes. Disease assessed on the flag leaf - Leaf 3 - at GS 75 days on December 21, 2023.

| Growth stage (GS), application date and fungicide treatment (L/ha) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tmt no.** | **Seed treatment** | **30.10.23 GS 32** | **26.11.23 GS 39** | **19.12.23 GS 65** | **% LAA[1] by STB** | **Lower C.I.[2]** | **Upper C.I[2]** | **%LAA[1] by Leaf Rust** | **Lower C.I.[2]** | **Upper C.I[2]** | **Yield (t/ha)** | **Lower C.I.[2]** | **Upper C.I[2]** |
| 1 | Bare seed | Nil | Nil | Nil | 13.8 | 11.7 | 15.9 | 0.1 | 0 | 0.1 | 10.6 | 10.2 | 10.9 |
| 2 | Poncho® + Suscon® Green + Bioshield® + Rancona® Dimension | Kestrel® (1.0) | Revystar® (1.5) | Prosaro® (1.0) | 0.4 | -1.8 | 2.5 | 0 | -0.1 | 0 | 13.4 | 13.0 | 13.7 |
| 3 | Bioshield® + F22-01 BP | Kestrel® (1.0) | Revystar® (1.5) | Prosaro® (1.0) | 0.7 | -1.5 | 2.8 | 0 | 0 | 0.1 | 12.9 | 12.5 | 13.2 |
| 4 | Poncho® + Suscon® Green + Bioshield® + Rancona® Dimension | Kestrel® (1.0) | Revystar® (1.5) | F21-03 BP | 0.9 | -1.2 | 3.1 | 0 | 0 | 0.1 | 13.2 | 12.9 | 13.6 |
| 5 | Bioshield® + F22-01 BP | Kestrel® (1.0) | Revystar® (1.5) | F21-03 BP | 0.4 | -1.7 | 2.6 | 0 | -0.1 | 0 | 12.4 | 12.0 | 12.7 |
| 6 | Poncho® + Suscon® Green + Bioshield® + Rancona® Dimension | Kestrel® (1.0) | Revystar® (1.5) | F21-04 BP | 0.9 | -1.2 | 3.1 | 0 | 0 | 0.1 | 13.3 | 12.9 | 13.6 |
| 7 | Bioshield® + F22-01 BP | Kestrel® (1.0) | Revystar® (1.5) | F21-04 BP | 0.8 | -1.3 | 2.9 | 0 | 0 | 0.1 | 12.0 | 11.7 | 12.4 |
| 8 | Poncho® + Suscon® Green + Bioshield® + Rancona® Dimension | F21-03 BP | Revystar® (1.5) | F21-03 BP | 1.5 | -0.6 | 3.6 | 0 | 0 | 0.1 | 12.9 | 12.5 | 13.2 |
| 9 | Bioshield® + F22-01 BP | F21-03 BP | Revystar® (1.5) | F21-03 BP | 0.7 | -1.4 | 2.8 | 0 | 0 | 0.1 | 12.2 | 11.9 | 12.6 |
| | | | | **Mean** | **2.24** | | | **0.018** | | | **12.5** | | |
| | | | | **P value** | **<0.001** | | | **0.237** | | | **<0.001** | | |
| | | | | **CV (%)** | | | | | | | **2.6** | | |

Note: Yellow indicates the treatments that were amongst those that produced the highest disease control. [1]LAA – leaf area affected by STB or leaf rust (differences between treatment means are expressed as 95% upper and lower confidence intervals). [2]C.I: confidence interval. Active ingredients: Poncho® (a.i. 600 g/L clothianidin, Group 4A insecticide); Suscon® Green (a.i. 100 g/L chlorpyrifos, Group 1 insecticide); Rancona® Dimension (a.i. 25 g/L ipconazole and 20 g/L metalaxyl, Group 3 and 4 fungicides); BioShield® (a.i. 4 x 1010 cfu/g Serratia entomophila; Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Prosaro® (a.i. 125 g/L prothioconazole and 125 g/L tebuconazole, Group 3 fungicide); Revystar® (a.i. 100 g/L mefentrifluconazole and 50 g/L fluxapyroxad, Group 3 and 7 fungicides).

**Table 7.** Percent leaf area affected by STB and leaf rust and grain yield for autumn sown wheat, cultivar 'SY Defiant', under dryland conditions at Chertsey, Mid Canterbury in 2023-24, following application of different fungicide programmes. Disease assessed on the flag leaf - Leaf 3 - at GS 75 on December 21, 2023

| Growth stage (GS), application date and fungicide treatment (L/ha) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tmt no. | Seed treatment | 30.10.23 GS 32 | 26.11.23 GS 39 | 19.12.23 GS 65 | % LAA[1] by STB | Lower C.I.[2] | Upper C.I[2] | %LAA[1] by Leaf Rust | Lower C.I.[2] | Upper C.I[2] | Yield (t/ha) | Lower C.I.[2] | Upper C.I[2] |
| 1 | Bare seed | Nil | Nil | Nil | 33.7 | 28.8 | 38.5 | 0.9 | 0.8 | 1.1 | 8.9 | 8.3 | 9.6 |
| 2 | Poncho® + Suscon® Green + Bioshield® + Rancona® Dimension | Kestrel® (1.0) | Revystar® (1.5) | Opus® (0.25) + Amistar® (0.25) | 17.4 | 12.5 | 22.2 | 0 | -0.1 | 0.2 | 9.7 | 9.0 | 10.3 |
| 3 | Bioshield® + F22-01 BP | Kestrel® (1.0) | Revystar® (1.5) | Opus® (0.25) + Amistar® (0.25) | 11.7 | 6.9 | 16.6 | 0 | -0.1 | 0.1 | 9.4 | 8.7 | 10.0 |
| 4 | Poncho® + Suscon® Green + Bioshield® + Rancona® Dimension | Kestrel® (1.0) | Revystar® (1.5) | F21-03 BP | 15.0 | 10.1 | 19.9 | 0 | -0.2 | 0.1 | 9.7 | 9.0 | 10.3 |
| 5 | Bioshield® + F22-01 BP | Kestrel® (1.0) | Revystar® (1.5) | F21-03 BP | 10.8 | 5.9 | 15.7 | 0 | -0.1 | 0.2 | 9.3 | 8.7 | 10.0 |
| 6 | Poncho® + Suscon® Green + Bioshield® + Rancona® Dimension | Kestrel® (1.0) | Revystar® (1.5) | F21-04 BP | 12.1 | 7.2 | 16.9 | 0 | -0.2 | 0.1 | 9.8 | 9.2 | 10.5 |
| 7 | Bioshield® + F22-01 BP | Kestrel® (1.0) | Revystar® (1.5) | F21-04 BP | 8.9 | 4.0 | 13.7 | 0 | -0.1 | 0.2 | 9.4 | 8.7 | 10.1 |
| 8 | Poncho® + Suscon® Green + Bioshield® + Rancona® Dimension | F21-03 BP | Revystar® (1.5) | F21-03 BP | 14.2 | 9.3 | 19.1 | 0 | -0.2 | 0.1 | 9.5 | 8.9 | 10.2 |
| 9 | Bioshield® + F22-01 BP | F21-03 BP | Revystar® (1.5) | F21-03 BP | 13.2 | 8.3 | 18.1 | 0.1 | -0.1 | 0.2 | 9.0 | 8.4 | 9.7 |
| | | | | **Mean** | **15.21** | | | **0.11** | | | **9.4** | | |
| | | | | **P value** | **<0.001** | | | **<0.001** | | | **<0.001** | | |
| | | | | **CV (%)** | | | | | | | **1.3** | | |

Note: Yellow indicates the treatments that were amongst those that produced the highest disease control. [1]LAA – leaf area affected by STB or leaf rust (differences between treatment means are expressed as 95% upper and lower confidence intervals). [2]C.I: confidence interval. Active ingredients: Poncho® (a.i. 600 g/L clothianidin, Group 4A insecticide); Suscon® Green (a.i. 100 g/L chlorpyrifos, Group 1 insecticide); Rancona® Dimension (a.i. 25 g/L ipconazole and 20 g/L metalaxyl, Group 3 and 4 fungicides); BioShield® (a.i. 4 x 1010 cfu/g Serratia entomophila. Amistar® (a.i. 250 g/L azoxystrobin, Group 11 fungicide); Kestrel® (a.i. 160 g/L prothioconazole and 80 g/L tebuconazole, Group 3 fungicide); Opus® (a.i. 125 g/L epoxiconazole, Group 3 fungicide); Revystar® (a.i. 100 g/L mefentrifluconazole and 50 g/L fluxapyroxad, Group 3 and 7 fungicides)

**Table 8.** Plant counts, grain yield and quality for autumn sown wheat, cultivar 'SY Defiant', with irrigation at Somerton, Mid Canterbury in 2023-24, following sowing with different seed treatments. All treatments were managed as per the treatment of the paddock except for seed treatments.

| Tmt no. | Seed Treatment | Plants ($m^2$) | Lower C.I.[1] | Upper C.I.[1] | Yield (t/ha) | Lower C.I.[1] | Upper C.I.[1] | TGW[2] (g) | Lower C.I.[1] | Upper C.I.[1] | Test weight (kg/hL) | Lower C.I.[1] | Upper C.I.[1] | Protein (%) | Lower C.I.[1] | Upper C.I.[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Bare seed | 134 | 115 | 153 | 13.0 | 12.7 | 13.3 | 51.4 | 49.9 | 52.8 | 76.4 | 75.6 | 77.2 | 9.1 | 8.7 | 9.6 |
| 2 | Poncho® | 129 | 110 | 148 | 13.4 | 13.1 | 13.7 | 50.7 | 49.2 | 52.1 | 76.0 | 75.2 | 76.8 | 9.5 | 9.1 | 9.9 |
| 3 | Poncho® + Kinto® Duo | 153 | 134 | 172 | 13.9 | 13.6 | 14.2 | 52.6 | 51.2 | 54.0 | 76.7 | 75.9 | 77.5 | 9.1 | 8.7 | 9.5 |
| 4 | Kinto® Duo | 155 | 136 | 174 | 13.7 | 13.4 | 14.0 | 53.5 | 52.0 | 54.9 | 76.6 | 75.8 | 77.4 | 9.4 | 9.0 | 9.8 |
| 5 | Bioshield® | 126 | 107 | 145 | 13.2 | 12.9 | 13.5 | 51.9 | 50.5 | 53.3 | 76.1 | 75.4 | 76.9 | 9.6 | 9.1 | 10.0 |
| 6 | Bioshield® + F22-02 BP | 102 | 83 | 121 | 12.7 | 12.4 | 13.0 | 51.4 | 50.0 | 52.8 | 76.4 | 75.7 | 77.2 | 9.6 | 9.2 | 10.1 |
| 7 | Bioshield® + F21-02 BP | 109 | 90 | 128 | 12.7 | 12.4 | 13.0 | 51.2 | 49.8 | 52.6 | 76.4 | 75.6 | 77.1 | 9.6 | 8.2 | 10.0 |
| 8 | Bioshield® + F22-01 BP | 132 | 113 | 151 | 13.2 | 12.9 | 13.5 | 5.21 | 49.8 | 52.6 | 76.4 | 75.6 | 77.2 | 9.5 | 9.1 | 9.9 |
| 9 | Bioshield® + F22-03 BP | 124 | 105 | 143 | 13.1 | 12.8 | 13.4 | 52.7 | 51.2 | 54.1 | 76.9 | 76.2 | 77.7 | 9.3 | 8.9 | 9.7 |
| 10 | Bioshield + Kinto® Duo | 142 | 123 | 161 | 13.8 | 13.5 | 14.1 | 52.6 | 51.1 | 54.0 | 76.8 | 76.0 | 77.6 | 9.6 | 9.1 | 10.0 |
| 11 | Poncho® + Bioshield® | 115 | 96 | 134 | 13.3 | 13.3 | 13.6 | 52.4 | 51.0 | 53.8 | 76.8 | 76.0 | 77.6 | 9.3 | 8.9 | 9.7 |
| 12 | Poncho® + F22-01 BP | 133 | 113 | 152 | 13.2 | 13.2 | 13.5 | 52.3 | 50.9 | 53.7 | 76.9 | 76.1 | 77.6 | 9.2 | 8.8 | 9.6 |
| 13 | Poncho® + Bioshield® + F22-01 BP | 128 | 108 | 147 | 13.4 | 13.1 | 13.7 | 52.9 | 51.5 | 54.3 | 76.6 | 75.8 | 77.4 | 9.3 | 8.9 | 9.7 |
| 14 | Poncho® + Bioshield® + Kinto® Duo | 141 | 122 | 160 | 13.7 | 13.7 | 13.9 | 53.5 | 52.0 | 54.9 | 76.6 | 75.8 | 77.4 | 9.1 | 8.7 | 9.6 |
| | **Mean** | **130** | | | **13.3** | | | **52.1** | | | **76.5** | | | **9.4** | | |
| | **P value** | **<0.001** | | | **<0.001** | | | **0.033** | | | **0.8** | | | **0.08** | | |
| | **CV (%)** | **-** | | | **1.4** | | | | | | | | | | | |

Note: Yellow indicates the treatments that were amongst those that produced the highest plant population, grain yield and quality. All treatments received the same foliar fungicide programme.
Active ingredients: Seed treatments: Poncho® (a.i. 600 g/L clothianidin, Group 4A insecticide); Kinto™ Duo (a.i. 20 g/L triticonazole and 60 g/L procloraz, Group 3 fungicide); F22-02 BP: *Trichoderma spp.* Fungicide Resistance Action Committee (FRAC) code: BM 02 fungicide: Biologicals with multiple modes of action: Microbial – fungal; multiple effects including but not exclusive to competition, mycoparasitism, antibiosis, membrane disruption by fungicidal lipopeptides, lytic enzymes, induced plant defence; F21-02 BP: *Trichoderma spp.* FRAC code BM 02 fungicide: Biologicals with multiple modes of action: Microbial – fungal; multiple effects including but not exclusive to competition, mycoparasitism, antibiosis, membrane disruption by fungicidal lipopeptides, lytic enzymes, induced plant defence; F22-01 BP: *Bacillus spp.* FRAC code BM 02 fungicide: Biologicals with multiple modes of action: Microbial – fungal; multiple effects including but not exclusive to competition, mycoparasitism, antibiosis, membrane disruption by fungicidal lipopeptides, lytic enzymes, induced plant defence; F22-03 BP: Biostimulant: peptide + organic nitrogen.

| Chemical trademarks | Label rate for Barley (L/ha) | Label rate for Wheat (L/ha) | Active ingredient (g ai/L) | Mode of Action Group | Withholding periods (days) Silage | Withholding periods (days) Grain |
|---|---|---|---|---|---|---|
| AgPro Azoxystrobin (AgPro NZ Ltd) | 0.75 | 0.75 | azoxystrobin 250 | 11 | 28 | 35 |
| Amistar® SC (Syngenta Crop Protection Ltd) | 0.75 | 0.75 | azoxystrobin 250 | 11 | 28 | 35 |
| Atlantis® Flo (Adria) | 0.75 | 0.75 | azoxystrobin 250 | 11 | 28 | 35 |
| Avior 250 SC (Kenso New Zealand Ltd) | 0.75 | 0.75 | azoxystrobin 250 | 11 | 28 | 35 |
| Azoxystar® (Grosafe) | 0.75 | 0.75 | azoxystrobin 250 | 11 | 28 | 35 |
| Inspire® (Ravensdown Fertiliser Co-Operative Ltd) | 0.75 | 0.75 | azoxystrobin 250 | 11 | 28 | 35 |
| Roxy® (Agri Solutions Ltd) | 0.75 | 0.75 | azoxystrobin 250 | 11 | 28 | 35 |
| Tazer® (Nufarm Ltd) | 0.75 | 0.75 | azoxystrobin 250 | 11 | 28 | 35 |
| Aviator Xpro® (Bayer Crop Science Ltd) | 0.7-10 | 0.7-10 | bixafen 150 + prothioconazole 150 | 7 + 3 | 42 | 56 |
| Elatus Plus® (Syngenta Crop Protection Ltd) | xx | 0.75 | benzovindiflupyr 100 | 7 | 28 | 42 |
| AgPro Guardian (AgPro NZ Ltd) | 0.3-0.5 | 0.3-0.5 | carbendazim 500 | 1 | None | 60 |
| Carbenz (Agri Solutions Ltd) | 0.3-0.5 | 0.3-0.5 | carbendazim 500 | 1 | None | 60 |
| Chief® (Adama NZ Ltd) | 0.3-0.5 | 0.3-0.5 | carbendazim 500 | 1 | None | 60 |
| Goldazim® 500 SC (Adria Crop Protection Ltd) | 0.3-0.5 | 0.3-0.5 | carbendazim 500 | 1 | None | 60 |
| MBC 500 FLO (UPL New Zealand Ltd) | 0.3-0.5 | 0.3-0.5 | carbendazim 500 | 1 | None | 60 |
| Protek® (Arxada NZ Ltd) | 0.3-0.5 | 0.3-0.5 | carbendazim 500 | 1 | 35 | 60 |
| Accuro® 125 SC (Adria Crop Protection Ltd) | 1 | 1 | epoxiconazole 125 | 3 | 28 | 42 |
| AgPro Epozole (AgPro NZ Ltd) | 1 | 1 | epoxiconazole 125 | 3 | 28 | 42 |
| Fortify 125® (Ravensdown Fertiliser Co-Operative Ltd) | 1 | 1 | epoxiconazole 125 | 3 | 28 | 42 |
| Opus® (BASF NZ Ltd) | 1 | 1 | epoxiconazole 125 | 3 | 28 | 42 |
| Stellar® (Adama NZ Ltd) | 1 | 1 | epoxiconazole 125 | 3 | 28 | 42 |
| Bolide® (Adama NZ Ltd) | 2 | 2 | epoxiconazole 225 + prochloraz 50 | 3 | 42 | 42 |
| Questar™ (Corteva Agriscience) | xx | 1.5-2.0 | fenpicoxamid 50 | 21 | 28 | None if used as directed |
| Imtrex® (BASF NZ Ltd) | 1.25 | 1.25 | fluxapyroxad 62.5 | 7 | 28 | 42 |
| Systiva® (BASF NZ Ltd) | 0.75-1.25 L/t seed | 0.75-1.25 L/t seed | fluxapyroxad 333 | 7 | 42 | 42 |
| Phoenix® (Adama NZ Ltd) | 1.5 | 1.5 | folpet 500 (g/kg) | M4 | 28 | Latest appl. GS 59 (barley) GS 39 (wheat) |
| Valeo® 500 SC (Adria Crop Protection Ltd) | 1.5 | 1.5 | folpet 500 (g/kg) | M4 | Do not use on green feed silage crops | None if used as directed |
| Caley Iblon® (Bayer Crop Science Ltd) | 1.5 | 1.5 | isoflucpyram 50 + prothioconazole 100 | 7 + 3 | 42 | 56 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Vimoy® Iblon® (Bayer Crop Science Ltd) | 1.5 | 1.5 | isoflucypram 50 | 7 | 42 | 56 |
| Seguris flexi® (Syngenta Crop Protection Ltd) | 0.6 | 0.6 or 1.0 (STB) | isopyrazam 125 | 7 | 28 | 42 |
| Revystar® (BASF NZ Ltd) | 1.5 | 1.5 | mefenitrifluconazole 100 + fluxapyroxad 50 | 3 + 7 | 28 | 42 |
| Acanto® (Corteva Agriscience) | 0.5 | 0.5-0.75 | picoxystrobin 250 | 11 | 28 | 35 |
| AgPro Thiozole (AgPro NZ Ltd) | 0.4-0.8 | 0.4-0.8 | prothioconazole 250 | 3 | 42 | 56 |
| Joust® (Nufarm Ltd) | 0.4-0.8 | 0.4-0.8 | prothioconazole 250 | 3 | 42 | 56 |
| Pilot™ 250 EC (Orion AgriScience Ltd) | 0.4-0.8 | 0.4-0.8 | prothioconazole 250 | 3 | 42 | 56 |
| Proline® (Bayer Crop Science Ltd) | 0.4-0.8 | 0.4-0.8 | prothioconazole 250 | 3 | 42 | 56 |
| Prothago® (Adama NZ Ltd) | 0.4-0.8 | 0.4-0.8 | prothioconazole 250 | 3 | 42 | 56 |
| Vitalis® (Adria Crop Protection Ltd) | 0.4-0.8 | 0.4-0.8 | prothioconazole 250 | 3 | 42 | 56 |
| Prosaro® (Bayer Crop Science Ltd) | 1 | 1 | prothioconazole 125 + tebuconazole 125 | 3 | 42 | 56 |
| Kestrel® (Bayer Crop Science Ltd) | 1 | 1-1.25 | prothioconazole 80 + tebuconazole 160 | 3 | 42 | 56 |
| Miravis® Flexi (Syngenta Crop Protection Ltd) | 1.2 | xx | pydiflumetofen 62.5 | 7 | 28 | 42 |
| Comet® (BASF NZ Ltd) | 0.8 | 0.8 | pyraclostrobin 250 | 11 | 28 | 56 |
| Convoy™ (Orion AgriScience Ltd) | 0.8 | 0.8 | pyraclostrobin 250 | 11 | 28 | 56 |
| Pryrax® (Adria Crop Protection Ltd) | 0.8 | 0.8 | pyraclostrobin 250 | 11 | 28 | 56 |
| Compass® (Orion AgriScience Ltd) | 0.44 | 0.44 | tebuconazole 430 | 7 | 28 | 49 |
| Folicur® (Syngenta Crop Protection Ltd) | 0.44 | 0.44 | tebuconazole 430 | 7 | 28 | 49 |
| Hornet® 430 SC (Nufarm Ltd) | 0.44 | 0.44 | tebuconazole 430 | 7 | 28 | 49 |
| Rebuke (Kenzo NZ) | 0.44 | 0.44 | tebuconazole 430 | 7 | 28 | 49 |

# Acknowledgements

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**Foundation for Arable Research**
PO Box 23133, Hornby, Christchurch 8441, New Zealand
Phone: +64 3 345 5783 • Fax: +64 3 341 7061 • Email: far@far.org.nz • Web: www.far.org.nz