Disease Management and Crop Canopies

What are the interactions?

A CEREAL CROP MANAGEMENT GUIDE

Grains Research & Development Corporation

www.grdc.com.au
Introduction
This guide brings together some of the principal results of a GRDC funded project entitled Optimising cereal profitability in the High Rainfall Zone through the integration of disease and canopy management principles (SFS00015). The booklet is a follow up to Cereal Growth Stages – the link to crop management that was released in September 2005. The information for this guide was generated in the High Rainfall Zone of Australia in 2005, 2006 and 2007, though a smaller number of project trials were carried out in the drier regions of South Australia (Hart) and in the Wimmera and Victorian Mallee. It should be emphasised that many of the trial results were subject to below average rainfall for the season in both 2006 and 2007.

The general theme running through the booklet is one of interactions, since a number of the project trials were set up to examine more than one variable. In the disease management section results are presented on the interaction between cultivar susceptibility and disease management strategy. In the canopy management sections results are presented on how the use of nitrogen influences the need for disease control. In addition, results on the performance of newer fungicide active ingredients on disease in wheat and barley are also presented. The booklet has four distinct sections:

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This booklet has been compiled by the project co-ordinator Nick Poole from the Foundation for Arable Research (FAR), with project work conducted by a number of different research and farming groups throughout Australia. These were at Southern Farming Systems (Col Hacking, Mark McDonald, Lou Ferrier, Rohan Wardle, Geoff Dean and Wes Arnott), Hart Field Site (Peter Hooper), Cropfacts/Birchip Cropping Group (Brooke White and Cherie Reilly), Harden Group (Jim Wright, Tony Good and Peter Hamblin), SARDI (Trent Potter and Matthew Hoskins), Kalyx (Peter Burgess), Ag Consulting Co (Bill Long and Danny Le Feuvre) and Mid North HRZ Group (Mick Faulkner).

Supplementary information came from a GRDC funded project in northern NSW where the collaborators were Agvance (Peter Mackenzie and Alan Bowring) and NSW DPI (Ron Southwell and Anthony Mitchell).

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ISBN 978-1-875477-47-0
Published June 2009
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1. Cereal growth stages – a refresher

Why are cereal growth stages important to cereal growers?

A growth stage key provides farmers, advisers and researchers with a common reference for describing the crop’s development. Management by growth stage is critical to optimise returns from inputs such as nitrogen (N), plant growth regulators (PGR), fungicides and water.

Zadoks cereal growth stage key

This is the most commonly used growth stage key for cereals in which the development of the cereal plant is divided into 10 distinct development phases covering 100 individual growth stages. Individual growth stages are denoted by the prefix GS (growth stage) or Z (Zadoks), for example GS39 or Z39.

Key growth stages for input application linked to disease control and canopy management

The principal inputs applied for manipulating crop canopies are applied at Zadoks growth stages GS30 - 39 the start of stem elongation through to flag leaf emergence. This period is important for both nitrogen timing and fungicide application to protect key leaves such as the flag leaf in wheat and flag minus 1 in barley (the leaf below the flag leaf). In order to ensure the correct identification of these growth stages, plant stems are cut longitudinally, so that internal movement of the nodes (joints in the stem) and lengths of internodes (hollow cavities in the stem) can be measured.

How long does it take for the key leaves to emerge?

One of the most frequently asked questions, is how long does it take for the key leaves such as flag leaf, flag minus 1 and flag minus 2 to emerge? The length of time taken for a leaf to emerge is called the PHYLLOCHRON and is driven by temperature. It is measured in day degrees (day °C) meaning that the length of time for leaf emergence in calendar days depends on the temperature.

Contribution of the key leaves to yield – how does it differ between the High Rainfall Zone and Mallee?

In the High Rainfall Zone (HRZ) the contribution of the top three leaves to yield is much greater than the same leaves of a cereal crop grown in the drier Mallee regions. In the HRZ there is much greater contribution to yield from post flowering leaf photosynthesis (that is, a longer grainfill period). In the Mallee crops there is less contribution from the leaves and relatively more from the stem, hence as a general rule disease infection of these leaves has less impact in the Mallee than in the HRZ. However stem rust is equally destructive in both environments if conditions for the disease prevail, since the greatest impact of this disease is on the stem, preventing carbohydrate reaching the ear.
1. Cereal Growth Stages – a refresher

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Germination, seedling establishment and leaf production GS00 -19

- The radicle and seminal roots are the first parts of the plant to develop during the germination process (GS05), followed by the coleoptile (embryo shoot) (GS07).
- Roots can be initiated from several positions on the seedling, both at the level of the seed and at the crown.
- The crown is usually separated from the seed by the sub-crown internode. The length of this internode increases as the depth of planting increases.
- After seedling emergence, leaves are produced at a rate of about one every 5 -14 days, depending on temperature experienced at the growing point.

- The number of leaves produced on the main stem (from 1st leaf emerged to flag leaf) varies from approximately 7 - 14 depending on variety, region and sowing date.
- Longer season wheat in Tasmania will produce more leaves than short season wheat in northern NSW. This has a major bearing on crop structure because of the link between leaf and tiller production (see adjacent).
- Particularly in longer season environments, earlier sowing will produce more leaves.

<table>
<thead>
<tr>
<th>Principal stage 0</th>
<th></th>
<th>Principal stage 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Secondary stage</strong></td>
<td><strong>Zadoks growth stage</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td><strong>Germination</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 00</td>
<td>Dry grain</td>
<td>0 10</td>
</tr>
<tr>
<td>1 01</td>
<td>Start of imbibition (water absorption)</td>
<td>1 11</td>
</tr>
<tr>
<td>5 05</td>
<td>Radicle emerged</td>
<td>2 12</td>
</tr>
<tr>
<td>7 07</td>
<td>Coleoptile emerged</td>
<td>3 13</td>
</tr>
<tr>
<td>9 09</td>
<td>Leaf just at coleoptile tip</td>
<td>4 14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 15</td>
</tr>
</tbody>
</table>
Tillering and early ear development GS21 - 30

- Tillering is an important development stage that allows the plant to compensate for low plant populations or take advantage of good growing conditions.
- The tiller number is closely linked with the number of leaves on the main shoot, since each leaf has a tiller bud at its base.
- The first tiller appears in the leaf axial of the oldest leaf at GS13 - 14.
- Note: in moisture stressed environments a cereal crop will not produce tillers, but instead only retain the main stem. In this case the plant is referred to by the number of leaves, for example 5 leaf stage GS15. The problem with noting the number of leaves instead of using the tillering stages method is that as old leaves die, it is difficult to accurately reference the plant, hence GS17-19 are rarely used.
- The number of tillers formed depends on the variety, growing conditions and time of sowing.
- The capability also exists to produce tillers from tillers (termed secondary tillers) if the plant is not crowded or is heavily fertilised.
- Tillers formed later are more likely to abort without producing grain; however this is dependent on sowing date and seed rate. The earlier the sowing and thinner the population the more likely later tillers will survive. Tillers that produce more than three leaves usually initiate their own root system. The proportion of initiated tillers that abort differs with each variety and can increase if the crop encounters stress conditions. It is also linked to when nitrogen is applied.
- During the time that tillering occurs, another less obvious but extremely important event occurs: the appearance of heads on the main shoot and tillers. Although the head at this stage is microscopic, the parts that will become the floral structures and future grain sites are already being formed.
- Terminal spikelet the last grain sites laid down on the embryo ear develops at GS31 (first node).

Stem and ear growth – (Stem elongation and booting) GS30 - 49

- Stem elongation occurs in response to temperature, day length and a period of cold weather-vernalisation (winter cultivars only). The exact balance of these three signals depends on cultivar, for example winter cereal cultivars v spring cereal cultivar.
- Each stem internode up the plant becomes progressively longer, and the last stem segment to elongate, the peduncle, accounts for a considerable proportion of the total stem length.
- Plant growth regulators that are designed to shorten plant stature and increase resistance to lodging are...
Head emergence and flowering
GS50 - 69

Even though stem elongation is classed as GS30 - 39, the stems are still elongating at head emergence. This is because the development and separation of the upper nodes (Zadoks GS35 (5th node) and GS36 (6th node) occur after flag leaf emergence GS37 - 39 (meaning that unfortunately the plant does not always proceed from GS00 - 99 in perfect chronological order).

As the stem continues to elongate, the head is pushed out of the flag leaf sheath, a stage referred to as “heading.” Within a few days of heading, flowering (pollination) begins in the head, starting first with the florets in the central spikelets (note in barley flowering can occur in the boot). Within the first few days flowering occurs both up and down the spike. Flowering commences with the anthers appearing from each floret, although this can change depending on the variety and weather conditions. If the anthers within a floret are yellow or grey rather than green, it is reasonably certain that pollination of the floret has occurred. The period of pollination within a single head is about four days under warm conditions. The grain within a head vary considerably in size and maintain this size variation throughout grain filling to maturity.
Grain fill and maturity GS70 - 99

Grain-fill progresses in three distinct phases over about four weeks under Australian conditions.
- In the first phase, the "watery ripe" (GS71) and "milk" stages, (GS73) the number of cells in the endosperm (the major starch and protein storage portion of the grain) are established. Little grain weight is accumulated during this phase.
- After pollination, the grain begins storing starch and protein rapidly and its dry weight increases in a nearly linear manner. This is when most of the final weight of the grain is accumulated. The grain consistency is "soft dough" during this time.
- Finally, growth rate of the kernel declines about three weeks into grain filling and its weight approaches a maximum attained at physiological maturity.
- As the kernel approaches maturity, its consistency becomes "hard dough."
- At physiological maturity moisture level continues to drop until at GS99 the plant contains seed at GS00.

<table>
<thead>
<tr>
<th>Principal stage 7</th>
<th>Description</th>
<th>Zadoks growth stage</th>
<th>Secondary stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Milk development in grain</td>
<td>1 71</td>
<td>Grain watery ripe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 73</td>
<td>Early milk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 75</td>
<td>Medium milk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 77</td>
<td>Late milk</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Principal stage 8</th>
<th>Description</th>
<th>Zadoks growth stage</th>
<th>Secondary stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dough development in grain</td>
<td>3 83</td>
<td>Early dough</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 87</td>
<td>Hard dough, head losing green colour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9 89</td>
<td>Approximate physiological maturity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Principal stage 9</th>
<th>Description</th>
<th>Zadoks growth stage</th>
<th>Secondary stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ripening</td>
<td>1 91</td>
<td>Grain hard (difficult to divide with thumbnail)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 92</td>
<td>Grain cannot be dented by thumbnail, harvest ripe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9 99</td>
<td>Fully ripened plant containing grain at GS00 in the ear.</td>
</tr>
</tbody>
</table>
Key growth stages for input application linked to disease control and canopy management

The principal inputs for manipulating crop canopies are applied at Zadoks growth stages GS30 - 39 on the main stem (the start of stem elongation through to flag leaf emergence). This period is important for both nitrogen timing and protection of key leaves, such as flag leaf in wheat and flag minus 1 in barley. In order to ensure the correct identification of these growth stages, plant stems are cut longitudinally, so that internal movement of the nodes (joints in the stem) and lengths of internodes (hollow cavities in the stem) can be measured.
Nodal growth stage link to emergence of key leaves in the crop canopy

The most important growth stages for fungicide application are often in the period GS30 - 39. This is when the top four leaves of the canopy are produced. Before the last leaf (flag leaf) is produced it can be difficult to identify the emerging leaf. Whilst this can be carried out with a simple dissection, it is possible to link the approximate emergence of key leaves with the nodal growth stages outlined previously.

How long does it take for the key leaves to emerge?

One of the most frequently asked questions in the field is how long does it take for the key leaves such as flag leaf, flag-1 and flag-2 to emerge?

The length of time taken for a leaf to emerge is called the phyllochron and is driven by temperature. It is measured in day degrees (°C days) meaning that the length of time for leaf emergence in calendar days depends on the temperature. Most wheat cultivars have phyllochrons of approximately 100 -120 day °C. For all crop models such as APSIM it is essential to have the correct phyllochron as well as the precise climate and soil data.

Example: If the crop is at GS32 and flag-2 is emerged, how long will it take before the flag leaf is emerged?

A simple calculation of average daily temperature is to take the maximum and minimum daily temperature and divide by two (maximum daily temp + minimum daily temp÷2). Therefore suppose that from GS32 to GS39 the average maximum temperature was 22°C and the average minimum was 13°C. It would take approximately 12 days for the flag leaf to emerge on a variety with a phyllochron of 105 day °C.

\[(\text{max daily temp } 22°C + \text{ min daily temp } 13°C/2) = 17.5 \text{ day °C}\]

Phyllochron 105 day °C divided by 17.5 day °C = 6 days per leaf

Thus 6 days from flag -2 at GS32 to the emergence of flag -1, with another 6 days until flag leaf emergence, hence a total of 12 days.

In reality since temperatures are warmer as spring progresses, it may be that there will be 7 days between flag -2 and flag-1 and only 5 days between flag – 1 and flag leaf emergence on the main stem.
In the High Rainfall Zone (HRZ) the contribution of the top three leaves to yield is much greater than in the drier Mallee regions. In the HRZ there is much greater contribution to yield from post flowering leaf activity (that is, a longer grainfill period). In the Mallee crops there is less contribution from the leaves and more from the stem, hence as a general rule disease infection of the leaf has less impact in the Mallee than in the HRZ. However stem rust is equally destructive in both environments if conditions for the disease prevail, since the greatest impact of the disease is on the stem.

### Contribution of the key leaves to yield – how does it differ between the HRZ and Mallee?

**When do foliar fungicides pay?**

Approximate yield contribution of top three leaves in wheat (HRZ v Mallee)

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<th>Mallee Contribution</th>
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<td>9%</td>
</tr>
<tr>
<td>Flag-1</td>
<td>43%</td>
<td>29%</td>
</tr>
<tr>
<td>Flag-2</td>
<td>7%</td>
<td>2%</td>
</tr>
<tr>
<td>Flag-3</td>
<td>3%</td>
<td>3%</td>
</tr>
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**Flag-1 + Flag-2:**

- **Stem + ear:** 56-80%
- **Flag:** 9-29%
- **Flag-1:** 23%
- **Flag-2:** 7%
- **Flag-3:** 3%

**Source:** HGCA, UK

1. **Winter wheat under higher rainfall:** top three leaves more important to yield
2. **Winter wheat < 3 t/ha in Mallee:** top three leaves less important to yield

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**Growth Stages**

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**Disease Management and Crop Canopies – what are the interactions?**
2. Disease management

How does disease control influence cultivar yield rankings in the High Rainfall Zone (HRZ)?

Trials over the last three years have clearly shown that the application of foliar fungicides changes yield ranking amongst the same varieties. Variety resistance is the easiest way for a farmer to control disease, but it may not always be the most profitable, unless the resistant cultivar has equal yield and quality potential to the more susceptible cultivar grown with a disease management package.

How does cultivar susceptibility influence fungicide strategy?

How do the effects of an upfront disease control strategy based on seed treatments and ‘in furrow products’ compare to disease control strategies based on foliar fungicides applied at key growth stage timings? Project results illustrate how different environments influence these choices. Greater cultivar resistance delays the build up of a disease epidemic and therefore influences the optimum time for disease control and strategy chosen.

Performance of new strobilurin and triazole fungicide products in wheat

Over the past three years there have been a number of new fungicide products introduced for use in Australian cereal crops. Products have included (for the first time) a strobilurin based Group 11 Quinone outside Inhibitor (QoI) fungicide Amistar Xtra®, newer triazole actives Group 3 Dimethylation Inhibitor (DMI) fungicides such as Opus® based on epoxiconazole and the new combination Tilt Xtra®, which contains the new active cyproconazole and the old standard propiconazole. Project work has compared these products to assess their relative strengths.

Stem Rust – the most destructive rust

Over the course of the project, stem rust raised its profile causing widespread concern that it could have been a major problem in 2006, as well as the continuing uncertainty over the Ug99 strain which originates in the horn of Africa. Though variety resistance remains the primary means of controlling this disease, project work did look at the influence of foliar fungicides on stem rust in the 2006 season. The work indicated that foliar fungicides do have an impact on this disease and that there are key differences in product performance. In addition, work conducted by others in the late ‘90s in WA has indicated that the window of cost effective timings is much wider than with other rusts, such as stripe rust.

New fungicide performance in barley

Trials in WA and SA have generated information on the performance of new fungicides against leaf rust and mildew.
How does disease control influence cultivar rankings in the HRZ?

Variety resistance, but not at any cost!

Following the 2002-03 stripe rust epidemic the message to growers was clear – move to resistant varieties to beat the disease and grow the most profitable crops. Five seasons later and with a new mutation of the WA stripe rust pathotype it has not always been easy for growers to use cultivars with superior disease resistance that are durable in the face of an ever changing pathogen. In addition, when moving to a resistant variety, the grower needs to be confident that the resistant cultivar will be as profitable as growing a more susceptible variety with a disease management package.

Results from the National Varieties Trials (NVT) illustrate the value of disease resistance cultivars. The NVT trials are not routinely managed using a fungicide program. Information from untreated and fungicide treated trials is necessary to determine which is the most profitable cultivar.

Work over the last three seasons has illustrated that the application of a fungicide program clearly changes both the rank order of performance and overall profitability of the cultivars chosen. The work carried out by Southern Farming Systems from 2005 - 2007 involved the same cereal varieties being treated and untreated in blocked variety trials.

Whilst the 2006 trial was subject to no disease pressure due to the dry conditions, the work demonstrated that the varieties Kellalac® (MR-MS for stripe rust) and Chara® (MS-S for stripe rust) were similar in performance to the resistant cultivar Sentinel® when left untreated but were clearly higher yielding with a disease management package. Therefore based purely on disease resistance the choice of Sentinel® was appropriate; however in terms of yield potential, adaption to the environment and market considerations Kellalac® and Chara® had greater productivity.

Key points:

- Fungicide application for disease control (in these trials stripe rust) changes the overall ranking and profitability of individual cultivars.
- Select resistant varieties where they can be proven to be more profitable than more disease susceptible options grown with a disease management package, particularly under higher rainfall conditions.
How does cultivar susceptibility influence fungicide strategy?

Where a cultivar is truly resistant to a disease then there will be no response to fungicide application, since fungicides only protect an inherent yield potential that would have been expressed in the absence of disease. In such cases it is easy to advise on how the fungicide strategy will be influenced by cultivar resistance status, no disease, therefore **no need to spray**. Of course it is important to make sure that the cultivar’s resistance is complete against all the major diseases prevalent in that region before disease management is dismissed. But where varieties are intermediate in their susceptibility to disease, how should the grower adjust the fungicide strategy compared to a susceptible variety? This question has been one of those addressed by GRDC project SFS00015.

**How should a fungicide strategy be adjusted to take account of different rates of disease development?**

Upfront disease control versus in crop control – how is this influenced by variety resistance?

Though hampered by drier seasons (2006 and 2007) in which disease had been less problematic, research showed that seed and in furrow treatments can have much the same effect on disease development as variety resistance. In essence they delay the onset of the disease. This has been very evident with project trials on stripe rust infection in wheat.

**Time of disease infection**

The greatest impact of a cultivar’s inherent resistance on the disease management strategy is the onset and speed of disease infection.

- **Greater susceptibility** → **Greater resistance**
- **Earlier onset of disease** → **Later onset of disease**
- **More rapid development** → **Less rapid development**

Earlier infections tend to be associated with greater disease susceptibility and result in the need for earlier intervention by the grower. Greater disease resistance delays the onset of a disease epidemic. Some cultivars will be more susceptible to disease early (seedling susceptibility) and then develop greater resistance at stem elongation: this is termed **adult plant resistance (APR)**. In these cases ensure that earlier sowing and increased disease prevalence does not destroy green leaf tissue on flag-2 and flag-1 prior to APR switching on.

**So why can’t upfront treatments give protection for the whole season?**

In some short season scenarios where crops become infected early and the subsequent grain fill period is curtailed by hot dry conditions, upfront treatments are the most cost effective option. However in longer season scenarios with higher rainfall, upfront options such as seed and in furrow treatments do not give sufficient protection to the three upper most leaves of the crop canopy (flag, flag-1 and flag-2). This is due to the lack of the active ingredient moving into the largest leaves of the crop. This can be seen in disease scores taken at ear emergence in the work presented. Where there is an early infection of stripe rust, older leaves generally show higher infection than younger leaves that have been exposed to the disease for less time. With upfront treatment the newer leaves, with less active ingredient to protect them, show higher infection. Therefore upfront treatments can give good disease control up until stem elongation, then as larger leaves emerge protection declines.

**So if you had a susceptible wheat cultivar or a moderately susceptible cultivar what would be the most appropriate strategy, an upfront option or an in-crop option assuming only one measure was possible?**
Flag leaf spray versus upfront measures – Disease control

With an upfront fungicide treatment disease infection is delayed, but protection tends to decline as the upper canopy leaves emerge, as a result of active ingredient dilution in these later forming leaves. In contrast, a foliar fungicide, in this example Opus® 250 ml/ha applied at flag leaf, protects the uppermost leaves of the plant by directly applying fungicide to the leaf tissue. However, since the curative (kickback) activity of foliar fungicides is limited to approximately 7-10 days, application at flag leaf would not be able to prevent early disease build up coinciding with the start of early stem elongation (GS30-31).

- The more susceptible the variety to the disease, for example H45, the more potential leaf loss before the flag leaf spray is applied.
- With more resistance, for example Drysdale®, the variety’s own resistance gives it greater protection until the flag leaf emergence spray.
- Under cool, wet grain fill conditions the foliar flag leaf spray (the red line in both diagrams), can give poor disease control using upfront measures initially, but better control later, irrespective of variety.
- As the variety’s inherent disease resistance increases, there was less benefit to adopting the upfront strategy for stripe rust control. The variety’s own protection removes the need for the control.

The yield differences in these examples relate strongly to the area under the disease curve. This area represents loss of green leaf, with the smaller area under the curve the greater the yield. With both varieties showing leaf loss (area under the disease curve) even with a foliar fungicide it is perhaps not surprising that none of the single treatments maximised yield in this trial.

In three trials conducted in the eastern states in 2005, the same seven identical treatments were applied to three varieties with different levels of resistance to stripe rust.

Therefore if the flag spray in the High Rainfall Zone regions is the single most important disease measure, how much yield benefit is there from treating before flag leaf, either with an upfront measure or an earlier spray?
Disease Management

Jockey® seed treatment based on 450 ml/100kg costed at $20/ha
Impact® in furrow 400 ml/ha costed $20/ha
Opus® 250 ml/ha GS39 costed $15/ha
Bayleton® 1.0l /ha GS32 costed at $5/ha.
Wheeling damage from foliar sprays based on 2.5% yield loss with $7.50/ha application cost for foliar sprays.
Grain at $300/tonne.

The mean results of these three trials confirmed the following:

**Key points:**

- **With high stripe rust pressure in the High Rainfall Zone**, a single foliar fungicide applied at flag leaf emergence (GS37 – 39) was more cost effective than the best upfront sowing options (Jockey® and Impact®) applied alone.

- **With a moderately susceptible variety** the benefit of the upfront treatment was diminished relative to the untreated crop. The variety’s natural resistance delayed disease expression until later in stem elongation, when the impact of the upfront treatments was significantly reduced due to the low concentration of fungicide in the top three leaves.

- **To optimise yield and profitability in stripe rust susceptible varieties**, the flag leaf spray needed to be preceded by a seed treatment/in furrow or a foliar fungicide applied at GS31 - 32 (first-second node) in order to combat the loss of green leaf area below the flag leaf (flag-1 and flag-2).

- **With a susceptible and moderately susceptible variety** there was little yield difference in performance between whether stripe rust infection pre flag leaf was controlled with an upfront measure (Jockey/Impact) or a stem elongation foliar spray.

- **Note that with the moderately susceptible varieties when stripe rust expressed itself later, the relative yield benefit of the earlier treatment (either foliar spray or seed treatment/in furrow) is largely reduced, since greater natural resistance delayed disease expression.**

- **The most profitable varieties in all three trials were the resistant varieties. With no stripe rust there was no response to fungicide.**

- **Where cultivars have poor seedling resistance to the disease and good APR it may be appropriate to protect the crop “upfront” or with a foliar fungicide at GS31 - 32 and rely on APR activity for later disease protection.**
But how does the relationship between flag leaf spray versus upfront measure differ in drier environments?

In drier regions, with shorter growing seasons, all responses to fungicides are reduced and the relative advantage to foliar fungicides is reduced or nullified. In these environments the yield difference between upfront and in-crop options is more evenly balanced, provided disease development is evident in the crop at pre flag leaf emergence. This was shown in Birchip Cropping Group demonstration work carried out in 2004 in the Wimmera when only 7.5mm of rain fell in October and two days topped 38°C.

Despite better stripe rust control on the flag leaf with Bumper and Opus® (applied at flag leaf emergence) than with Impact, the benefit in disease control was not translated into yield since, unlike the longer growing season/HRZ scenario in 2005, grain fill was curtailed by dry conditions.

This balance in disease control between upfront options and a single flag spray can be presented as a schematic.

Suppose stripe rust infects at the start of stem elongation (GS30 - 32). In the wetter longer season scenario (of HRZ southern Victoria, NSW and SA) a single foliar fungicide is much more effective at preventing stripe rust during grain fill than a single upfront such as Impact. But in a shorter season scenario (Mallee), a shorter grain fill gives less opportunity for the foliar fungicide to be superior and any leaf loss before flag leaf will be better controlled by the seed treatment.

Key points:

- Early stripe rust infection pre flag leaf emergence, combined with short season scenarios reduce fungicide response overall (when compared to the HRZ/long season situations) and produce a more even weighting of benefits between a single in-crop fungicide and an upfront seed treatment or in-furrow product.
- This is because the control of stripe rust up to flowering is as important as the stripe rust control post flowering.

Yellow leaf spot in Yipti WA 2005 - No significant response to fungicide was obtained in the trial despite the disease.
Best strategy in the absence of disease

Over the three seasons of the project there were many trials that generated no response to fungicides. For example, in 2005 wheat trials in the West Australian HRZ (Albany to Esperance) expressed no disease, therefore it was not surprising that the most cost effective treatments in these trials were the untreated crops. The same was true of the eastern states HRZ in 2006.

In the no disease scenario it is worth focusing on the project results from trials which were affected with disease, since these illustrate no disadvantage to a timely foliar spray program based on growth stage compared to an upfront treatment. The foliar spray program enables the grower to assess and respond to the season in spring when the full extent of foliar disease pressure is more apparent.

Key points:
- In HRZ stripe rust situations there has been no disadvantage to foliar fungicide being applied at stem elongation stage. Therefore input insurance against disease may be better delayed until spring when the grower has a better understanding of how the season is shaping up.
- The exception to this is where upfront measures such as Jockey® or Impact® are being applied for root diseases such as take-all, or where seed treatment is applied routinely for seed-borne disease or BYDV control.

Foliar fungicide sprays versus upfront measures in HRZ barley production – what is the effect of cultivar resistance?

There are a number of key differences between barley and wheat when determining a disease control strategy – upfront (seed treatment/in furrow) as opposed to foliar fungicides.

- Firstly, the important crop canopy leaves for disease protection emerge at an earlier growth stage in barley than in wheat (earlier in stem elongation GS30 – 33), since the flag leaf is smaller and much less important.
- The use of upfront measures are less effective on barley net blotch diseases than equivalent choices in wheat for stripe rust.
- The range of diseases in HRZ barley production are far more diverse than in wheat, since powdery mildew (Blumeria graminis), leaf rust (Puccinia hordei), scald (Rhynchosporium secalis) and net blotch (Pyrenophora teres f. maculate) can be problematic early in the life of the crop.

Work conducted at South Stirling, WA in 2005, 2006 and at Naracoorte, SA in 2007 illustrated that other than the obvious effect of greater variety resistance reducing fungicide response, cultivar resistance had less effect on the cost effectiveness of upfront versus in crop foliar sprays.

In WA the principal diseases were powdery mildew (Blumeria graminis), net blotch (Pyrenophora teres f. maculate) and leaf rust (Puccinia hordei). Despite good control of powdery mildew from Impact® in furrow through the winter/early spring in 2005 and in spring 2006, the final impact on yield was minor.

Influence of fungicide strategy on yield performance of Mitre® (MS-S), Kellalac® (MR-MS) and Amarok (R ® ) – Inverleigh, Southern Victoria 2006

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>VS-S</td>
<td>4.01</td>
<td>4.13</td>
<td>4.39</td>
<td>3.94</td>
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<tr>
<td>MR-MS</td>
<td>3.78</td>
<td>3.70</td>
<td>3.57</td>
<td>3.71</td>
<td>3.69</td>
<td>3.77</td>
<td>3.68</td>
</tr>
<tr>
<td>R</td>
<td>3.15</td>
<td>2.88</td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

* Amarok was R in 2006, now it is MR-MS due to the 2007 Yr17 virulent pathotype
Disease Management

In 2005 two foliar sprays were significantly better than Impact® followed by one foliar spray. In 2006 there was no significant difference between the approaches. So how important was disease control prior to the start of stem elongation at GS30 - 31 in barley?

This was tested in 2006 and 2007 by preceding a two spray foliar program (starting at first node (GS31) followed by GS49) with an upfront measure of Impact® or a Group 3 DMI fungicide treatment. In WA there was no benefit from Impact® when the primary diseases were powdery mildew and leaf rust. In SA in 2007, there were still some yield benefits of using a Group 3 DMI fungicide treatment despite two foliar sprays, although this could not be related to differences in disease control.

Influence of new generation fungicides on two spray approaches in HRZ barley production using different cultivars.

The next section of the booklet will examine new generation fungicides in more detail. As part of the variety fungicide interaction studies in the project, the strobilurin based fungicide Amistar Xtra® has been compared to triazole chemistry (Tilt® – propiconazole and Opus® – epoxiconazole). Results showed that if leaf rust is present in susceptible and moderately susceptible varieties then appropriate doses of the new strobilurin fungicide can be extremely cost effective, compared to using older standards such as Tilt®.

Key points:

- In barley a single foliar fungicide applied at GS33 when the most important leaf is emerging (flag-1) had a greater impact on yield and margin than the upfront measure (Impact® in furrow).
- Better green leaf retention during grain fill was more important than disease control prior to the start of stem elongation (GS30 - 31). Results illustrated the benefit of applying two foliar fungicides instead of using single or double input approaches such as upfront followed by a single foliar spray or upfronts only.
- If the use of the upfront treatment for foliar disease control can be easily justified in terms of cost (less than $5/ha), then it may be cost effective to use these treatments. However it is clear from the data on barley that the impact of early foliar disease control using seed treatments and/or in furrow is small or negligible compared to foliar fungicide application.
- In the presence of leaf rust in barley two spray programs of Amistar Xtra® at 200 ml/ha offer considerable yield advantages over upfronts with or without single foliar follow ups or two foliar sprays based on older chemistry.

Mean yield of three varieties (Baudin, Gairdner, Gairdner Plus), f.b. = followed by
Performance of new strobilurin and triazole fungicide products in wheat

Over the past three years there have been a number of new fungicide products introduced for use in Australian cereal crops. For the first time products tested have included a strobilurin based fungicide Amistar Xtra®, newer triazole actives such as Opus® based on epoxiconazole and the new combination Tilt Xtra®, which contains the triazole cyproconazole and the old standard propiconazole (Tilt®). Project work has compared these products to assess their relative strengths in WA and SA.

Technical Profile

All three fungicides are sold as broad spectrum fungicides for use in broadacre cereals.

<table>
<thead>
<tr>
<th>Brand</th>
<th>Form</th>
<th>Active ingredients applied at common use rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilt Xtra® 330</td>
<td>EC</td>
<td>500 ml/ha = cyproconazole 40 g/ha ai + propiconazole 125 g/ha ai</td>
</tr>
<tr>
<td>Amistar Xtra® 280</td>
<td>SC</td>
<td>400 ml/ha = azoxystrobin 80 g/ha ai + cyproconazole 32 g/ha ai</td>
</tr>
<tr>
<td>Opus® 125</td>
<td>SC</td>
<td>250 ml/ha = epoxiconazole 31.25 g/ha ai</td>
</tr>
</tbody>
</table>

Since these actives are foliar fungicides they have been tested in one and two spray programs.
New fungicide performance on stripe rust in wheat

**Stripe rust**

*(Puccinia striiformis)*

Latent Period: Approx. 10-14 days at 15°C

Summer host: Volunteer Wheat

Winter host: Wheat and barley grass (barley grass stripe rust detected in eastern Australia but not in west)

Stripe rust spores do not require free water to germinate unlike leaf rust and stem rust. Can germinate in as little as 6-8 hours when temperatures are between 5-15°C. In winter spores tend to clump together (giving rise to hot spots) whilst in spring spores disperse giving more uniform infection.

In the stripe rust susceptible variety H45® grown at Scaddan, WA, fungicide application produced profit margins, after fungicide costs, ranging from $73 – $288/ha, despite lack of disease pressure until early ear emergence. The basis of this increased return was stripe rust control in the foliage and ear, leading to superior green leaf retention during grain fill. In terms of product performance there was no statistical difference between the three products in this trial, though there was a yield trend in favour of Amistar Xtra® being superior to Opus® which was superior to Bayleton® in this trial, though there was a yield difference between the three products during grain fill. In terms of product leading to superior green leaf retention stripe rust control in the foliage and ear, the basis of this increased return was an application produced profit margins, Y yield t/ha.

### Percentage stripe rust on flag (41 DAA GS32 and 13 DAA GS57)

**Graph 20**

Un treated

Un treated

H45® - Sprayed at GS39 (31 days before) with Opus® 250 ml/ha. Photo demonstrates that stripe rust was not fully controlled on side tillers (circled) since flag leaves were not emerged at application (unlike main stem flag leaf above).

One of the benefits of a two spray program is that a second spray can be applied to the head and flag together GS55 - 59. A single spray at flag leaf (GS59) leaves the flag leaves of the side tillers untreated since these were un emerged when the main stem flag leaf was sprayed.

A single application when the main stem flag leaf has emerged means unemerged side (secondary) tillers at the time of application remain untreated.

### Influence of fungicide application for stripe rust control (1 and 2 sprays) – Scaddan 2006 cv H45®

**Graph 19**

- Green bars appear to be aberrant results so should be treated with caution.

<table>
<thead>
<tr>
<th>Fungicide Application</th>
<th>Yield t/ha</th>
<th>LSD 4.67</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayleton® - 500ml/ha</td>
<td>6.44</td>
<td>3.75</td>
</tr>
<tr>
<td>Bayleton® - 1000ml/ha</td>
<td>6.88</td>
<td>3.32</td>
</tr>
<tr>
<td>Opus® - 250ml/ha</td>
<td>4.02</td>
<td>2.54</td>
</tr>
<tr>
<td>Amistar Xtra® - 400ml/ha</td>
<td>5.16</td>
<td>3.52</td>
</tr>
<tr>
<td>Amistar Xtra® - 800ml/ha</td>
<td>5.08</td>
<td>3.50</td>
</tr>
<tr>
<td>Control</td>
<td>2.2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percentage stripe rust on flag</th>
<th>GS57 Application</th>
<th>GS32 + 57 Application</th>
<th>LSD 4.8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayleton® - 500ml/ha</td>
<td>4.5</td>
<td>4.16</td>
<td>3.52</td>
</tr>
<tr>
<td>Bayleton® - 1000ml/ha</td>
<td>4.5</td>
<td>4.34</td>
<td>4.16</td>
</tr>
<tr>
<td>Opus® - 250ml/ha</td>
<td>2.2</td>
<td>2.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Amistar Xtra® - 400ml/ha</td>
<td>0.3</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Amistar Xtra® - 800ml/ha</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Control</td>
<td>10.0</td>
<td>10.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Stem Rust – the most destructive rust

**Stem rust**

(Puccinia graminis f. sp tritici)

- **Latent Period** (time between spore landing and symptoms visible): Approx 7-10 days at 25°C
- **Summer host**: Volunteer wheat and barley (barley is susceptible at high temperatures)
- **Winter host**: Wheat and triticale
- **Spore dispersal**: Air-borne spores
- Stem rust spores require free water to germinate.

During the project stem rust disease outbreaks created widespread concern. Even though variety resistance remains the primary means of controlling this disease, project work did look at the influence of foliar fungicides on stem rust in the 2006 season. The work indicated that foliar fungicides do have an impact on this disease and that there are key differences in product performance. In addition, work conducted by others in the late ‘90s in WA, showed that the window of cost effective timings is much wider than with other rusts, such as stripe rust.

Stem rust is an obligate parasite dependent on cereal volunteers alone in Australia. The disease has dark brown pustules on leaves (both upper and lower surfaces), leaf sheaths, stems and heads. Disease spread is more rapid later in the season from ear emergence onwards, when temperatures of 18-25°C favour spore generation. The disease can infect both barley and wheat and there is a separate subspecies for oats. Infection became evident at the end of the 2005 growing season when self sown volunteers appeared. It is widely accepted that the 2006 drought averted a major epidemic of the disease, since despite the extremely dry conditions there was still low level disease development experienced in some regions.

**Product Timing**

One of the few other studies carried out was conducted by Rob Loughman and his team in WA. Their work indicated that later fungicide timing for stem rust (not considered economic for other diseases) was still cost effective if stem rust was the principal disease present.

In addition, results from the three trial studies demonstrated that application at early detection stage gave the best control. However if the first application was applied before any of the ear had emerged, a second spray would reduce disease still further in those seasons favourable for the disease.

**Influence of fungicide application timing and rate on stem rust infection of the peduncle and the subsequent yield t/ha – WA 1999 cv Westonia (Loughman et al 2005)**

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Peduncle Infection</th>
<th>Yield t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>1.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Folicur 1</td>
<td>4 5 ml/ha GS47</td>
<td>2.8</td>
</tr>
<tr>
<td>Folicur 2</td>
<td>9 0 ml/ha GS47</td>
<td>2.8</td>
</tr>
<tr>
<td>Folicur 1</td>
<td>4 5 ml/ha GS71</td>
<td>2.8</td>
</tr>
<tr>
<td>Folicur 2</td>
<td>9 0 ml/ha GS71</td>
<td>3.3</td>
</tr>
</tbody>
</table>

GS47 – booting stage and GS71 – water ripe grain fill stage
Disease management decisions – products and timings for stem rust control

Product performance

In 2006 two trials were set up in self sown wheat volunteers in commercial paddocks on Yorke Peninsula and Eyre Peninsula, SA. Each trial used an identical treatment list to evaluate the performance of six fungicide products at three application rates against stem rust (Puccinia graminis f.sp. tritici). The trials were not taken to yield but examined product efficacy against the disease. The trials were sprayed when the majority of volunteers were at ear emergence GS59. Although this represented a typical growth stage for fungicide application in a wheat crop, disease development may have reduced in the volunteers due to cooling temperatures in late autumn.

Over the principal period that the trials were assessed, the average maximum daily temperatures taken from nearest BOM weather stations were approximately 18-19°C.

Of the two trials the Minlaton location provided the more even infection pressure. At this site disease levels on flag-2 increased from just less than 10% at the 13 day assessment to approximately 35% infection at the 28 day assessment, despite maximum temperatures for May averaging only 18°C in these regions. All fungicide treatments, irrespective of application rate, significantly reduced disease severity.

Examining the data in terms of disease incidence (% stems showing active infection), similar response patterns were revealed to those for severity.

At full label rate for stem rust control, Tilt® (500 ml/ha) was significantly inferior to Folicur® (290 ml/ha). Tilt Xtra® was superior to Tilt® (53% infection as opposed to 73% stem infected) but this difference was not statistically significant. Folicur® appeared to be the strongest product, although showed dose rate sensitivity with significant fall off in activity as rates were lowered.

Further product comparison studies conducted the following spring again illustrated the good performance of tebuconazole (Folicur®).

Influence of fungicide product on stem rust infection – Minlaton, SA 2006 cv Yipti

Rates: Low rate Folicur® 145ml/ha, High rate Folicur® 290ml/ha, Tilt Xtra® 250ml/ha.

Product performance on stem rust

Percentage active stem rust on the flag minus 2 leaf sheath – assessed as % leaf sheath area covered with active infection 28 days after application – cv Yipti, Minlaton, SA. 2006.

Percentage active stem rust incidence – assessed as % stems showing some degree of active infection 28 days after application – cv Yipti, Minlaton, SA. 2006.
Key points:

Fungicide timing for stem rust:
- Spraying for stem rust can be economic at a later growth stage than other diseases (e.g. stripe rust).
- Yield increases of 56% have been obtained from GS71 (watery ripe stage) applications (WA).
- Fungicide is effective at preventing subsequent infection when stem rust severity is slight on the plant parts to be protected.
- Early sprays on the leaf sheath GS45 - 51 are more effective for stem rust infection.
- Later sprays on the peduncle GS55 - 75 are more effective for stem rust disease.
- Optimum single timing appears to be centred around ear emergence GS55 - 59.

However:
- If infection is building up on leaf sheaths then a flag – late boot spray (GS39 - 51 spray) may be necessary.
  or
- If another disease requires application of a flag spray then this will control early stem rust infection, provided the product is suited. If ideal conditions persist for disease development, a GS39 - 51 spray will not control the disease on the peduncle and ear itself.

Product comparison against stem rust (results from 2006 trial comparisons):
- One of the Group 3 DMI fungicides and Tilt® had significantly higher levels of disease than low rate Folicur® (145ml), Tilt Xtra® (250ml) and two of the trial fungicides applied.
- At full label rate for stem rust control Tilt® (500 ml/ha) gave significantly inferior disease control to high rate Folicur® 290ml/ha.
- Though Folicur® gave the best disease control, all were dose rate sensitive; higher doses clearly gave better disease control.

Unlike other rusts the severe impact of stem rust will be expressed in crops with a low yield potential as well as in the high rainfall areas.
If a high disease incidence is recorded prior to ear emergence usually in the GS39 - 51 period, a foliar fungicide will reduce subsequent disease severity. A second fungicide spray may be needed to cover those parts of the plant un-emerged at the time of the first application.
The New Zealand ‘Straddle” approach (based on GS33 and 59 fungicides) may be an ideal way to counter both early stripe rust and stem rust, provided the stripe rust infection is not severe early in the season (GS30 - 31).
Performance of new strobilurin and triazole fungicide products in barley
The following information was generated in project trials where leaf rust and mildew infection was present in barley from 2005–2007

Leaf rust
(Puccinia triticina – wheat
P. hordei – barley)
Latent Period: Approx 7–10 days at 20°C
Summer host: Volunteer wheat and barley
Winter host: Wheat and barley
Spore dispersal: Air-borne spores
Leaf rust spores require free water to germinate.
Obligate parasite requiring volunteer hosts between crops. The disease is favoured by higher temperatures than stripe rust, hence usually more problematic in the second half of the growing season. Orange brown pustules larger than stripe rust but smaller than stem rust randomly distributed on upper leaf surfaces and leaf sheaths predominately. Different species for barley and wheat result in no cross infection. On occasions the disease is easier to detect on lower leaves due to “green island effect”. Dying leaves at the base of the canopy can be a good indicator of whether the crop is under disease pressure, since leaf rust pustule areas show up as green dots on the leaf where the fungus excretes sugars in order to keep the plant cells alive (obligate parasite).
Alternative host present in parts of South Australia (Star of Bethlehem).

Leaf rust 1.3% infection F-2 at GS49

Work in both SA and WA in 2005 and 2006 demonstrated that if a single spray was applied at GS33 (third node as flag – 1 emerges), the strobilurin Amistar Xtra® offered greater yield and disease control benefits (relative to the triazole based actives, Opus® and Tilt Xtra®) than it did in two spray programs. When used as two spray programs the Amistar® advantage over Tilt Xtra® and Opus® was less with the higher cost of the product frequently cancelling out any yield advantage. A lower dose of Amistar Xtra® applied twice would make timing less crucial than the single dose.
The correlation between green leaf loss in barley (due to leaf rust) at the end of flowering (GS69) and yield was extremely strong in the WA trial in 2006.
New fungicide performance on powdery mildew in barley

**Mildew**  
_(Blumina graminis)_

Latent Period: Approx 7 days at 15°C  
Summer host: Volunteer wheat and barley/barley grass and resting spores on straw  
In Crop: Wheat and barley forms of the disease are almost identical but do not cross infect. 
Spore dispersal: Resting spores rain splashed initially, air-borne spores (conidia) main in-crop infection.

Mildew tends to be more problematic in barley than in wheat particularly in the High Rainfall Zones. Straw and stubble borne black resting spores (cleistothecia) produce rain splashed spores, which infect volunteers and in turn provide wind blown spores which could infect new crops. Cool 10-20°C, cloudy and humid conditions favour development with maximum spore production at 20°C. Whilst rainfall can increase canopy humidity, heavy rain can also provide some control by washing the spores (conidia) off the leaf. 

In a powdery mildew situation such as that recorded in barley in WA in 2007, Amistar Xtra® did not offer the same yield advantages as with leaf rust. In this scenario there was little difference in yield response between products. It was also apparent that overall mildew infection had less impact on yield than leaf rust had in the previous season.

**Key points:**  
Two sprays (GS31 - 49) against mildew and leaf rust in WA were more cost effective than single sprays applied at GS33 based on product comparison trials in 2006 and 2007 on Baudin®.

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**Influence of three newer generation fungicides on yield t/ha – cv Baudin®, Munglinup, WA 2007**

<table>
<thead>
<tr>
<th>Fungicide</th>
<th>Yield t/ha</th>
<th>LSD 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilt Xtra® less than labelled rate</td>
<td>3.81</td>
<td>1.70</td>
</tr>
<tr>
<td>Tilt Xtra® 3L/ha</td>
<td>3.85</td>
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</tr>
<tr>
<td>Tilt Xtra® 5L/ha</td>
<td>3.85</td>
<td></td>
</tr>
<tr>
<td>Opus® less than labelled rate</td>
<td>3.58</td>
<td>1.58</td>
</tr>
<tr>
<td>Opus® 3L/ha</td>
<td>3.75</td>
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<td>Opus® 5L/ha</td>
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<tr>
<td>Amistar Xtra® less than labelled rate</td>
<td>3.90</td>
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<tr>
<td>Amistar Xtra® 400L/ha</td>
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</tr>
<tr>
<td>Amistar Xtra® 800L/ha</td>
<td>3.82</td>
<td></td>
</tr>
<tr>
<td>Tilt Xtra® less than labelled rate</td>
<td>3.78</td>
<td>1.78</td>
</tr>
<tr>
<td>Tilt Xtra® 3L/ha x 2</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>Tilt Xtra® 5L/ha x 2</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>Opus® less than labelled rate</td>
<td>3.75</td>
<td>1.75</td>
</tr>
<tr>
<td>Opus® 3L/ha x 2</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>Opus® 5L/ha x 2</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>Amistar Xtra® less than labelled rate</td>
<td>3.77</td>
<td>1.77</td>
</tr>
<tr>
<td>Amistar Xtra® 400L/ha x 2</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>Amistar Xtra® 800L/ha x 2</td>
<td>3.75</td>
<td></td>
</tr>
<tr>
<td>Untreated</td>
<td>3.47</td>
<td>1.47</td>
</tr>
</tbody>
</table>

**Graph 27**

Mildew 0.8% infection on F-2 at GS49

Influence of fungicide strategy on powdery mildew in barley 2007 in WA (2 spray foliar program (Amistar Xtra®, 400 ml/ha x 2) on left, single spray 3 centre samples and untreated on right)
3. Canopy Management

What is Canopy Management and what are the key ingredients for success?

Canopy management is managing the green surface area of the crop canopy in order to optimise profitability (crop yield and inputs). Canopy management is more than just delayed nitrogen application. Whilst nitrogen timing and rate is a key component of successful management, it is essential that it is considered in conjunction with soil moisture, soil nitrogen reserve, planting date, planting rate and cultivar, all of which are inter-related. To practice canopy management it is important to understand the principal interactions and those tools that can quantify the key factors and their interactions, from simple visual indicators through to crop models.

A Tactical Nitrogen Strategy, what is it, when and where should it be used?

One of the key features of the focus on canopy management in cereals has been the adoption of a tactical nitrogen approach, where nitrogen has been delayed from seeding until the start of stem elongation (GS30 - 31). In the recent run of droughts this technique resulted in considerable savings as growers took stock of the deteriorating season and did not apply nitrogen in the spring. In seasons where rainfall is less limited where has this technique been most successful?

How does row width interact with some of principles of Canopy Management?

Much of the work on canopy manipulation and tactical nitrogen timings at stem elongation have been carried out on narrow row spacing in the High Rainfall Zone. How do these management techniques work if cereal crops are sown in wider rows and in drier country?
What is Canopy Management?

Canopy management is managing the green surface area of the crop canopy in order to optimise profitability.

As a grower or adviser how can I manage the cereal crop canopy?

For most growers in Australia the concept has revolved around whether or not to adopt tactical nitrogen, that is delaying nitrogen application until spring. This has produced some useful results both in terms of more efficient N use and in avoiding nitrogen use when seasonal prospects have deteriorated in spring.

However, successful canopy management is more than just delayed nitrogen application. It is essential that it is considered in conjunction with soil moisture, soil nitrogen reserve, planting date and seeding rate, all of which are inter-related.

So how do the more important factors in canopy management interact?

In many ways the complexity of the answer to this question is why crop models are frequently employed to simulate crop growth. However there were some key factors in this project which ensure the successful management of the crop canopy.

Factors under grower control that influence canopy density, size and duration

<table>
<thead>
<tr>
<th>Larger/thicker canopies</th>
<th>Smaller/thinner canopies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher seedrates</td>
<td>Lower seedrates</td>
</tr>
<tr>
<td>More nitrogen</td>
<td>Less nitrogen</td>
</tr>
<tr>
<td>Earlier nitrogen</td>
<td>Later nitrogen (longer duration)</td>
</tr>
<tr>
<td>Early sowing</td>
<td>Later sowing</td>
</tr>
<tr>
<td>First wheats</td>
<td>Second wheats</td>
</tr>
<tr>
<td>Irrigated</td>
<td>Dryland</td>
</tr>
<tr>
<td>Longer season cultivars</td>
<td>Short season cultivars</td>
</tr>
</tbody>
</table>

GAI = Green area index (amount of green surface area)

Assuming water is not a variable under the growers control, it is the first four statements over which the grower has most control, and in principal the means by which growers can practice canopy management.

What are the key ingredients for success?

1. Recognition of the key growth stages for input application
2. Knowledge of soil moisture status
3. Soil nitrogen reserve and supply – deep soil nitrogen testing.
4. Planting date and planting rate.

Limited soil moisture will support smaller canopies and have a shorter grain fill period.

Smaller canopies will require less nutrition input.

Smaller canopies generally give rise to less disease pressure (less humidity).

Fungicide need will be reduced by lower disease pressure and a shorter grain fill period.

1. Recognition of the key growth stages for input application

Most inputs that manipulate the canopy are applied during stem elongation – pseudo stem erect to flag leaf emergence (from GS30 - GS39). Be able to recognise these growth stages (see section 1.0).

2. Knowledge of soil moisture status

In order to manage any cereal canopy with inputs during stem elongation the grower needs to be aware of soil moisture levels. How does it compare with the norm. What decile is our region recording (Decile 1; in line with the driest 10% of years on record. Decile 9; as wet as the wettest 10% of years on record) based on your region’s weather database, that is, how does this season rate against the previous spring?

Most crop canopies can look exceptionally good at the start of stem elongation since they have used little N or soil moisture by this growth stage. However from GS30 onwards canopy expansion is rapid and soil nitrogen reserves and soil water are consumed rapidly and canopies show some variability.

If soil moisture is limited at the start of stem elongation you will be unable to manipulate the crop canopy with nitrogen, therefore the best canopy management is not to apply inputs.
3. Soil nitrogen reserves and supply – deep soil nitrogen testing

Having knowledge of your soil nitrogen reserves and, even better, soil nitrogen supply (what is available to the plant after subsoil constraints and rooting depth is considered) is essential for canopy management.

You cannot practice canopy management unless you monitor soil nitrogen levels.

Delaying nitrogen inputs until stem elongation may not be successful unless you are aware of what soil nitrogen reserves you have at planting. In addition, soil nitrogen tests carried out at the end of summer 2 months before planting may reveal less soil nitrogen than tests carried out later in the autumn, when autumn rains have mineralised more reserves (a feature noted on some farms following the early break in 2007).

Whilst you need relatively small amounts of nitrogen to take the crop through to stem elongation 40-50kg N/ha, it is important to recognise that higher soil nitrogen reserves give you much more flexibility in managing the canopy with tactical nitrogen applied during stem elongation.

Using the visual appearance of the crop to help determine soil nitrogen supply

Providing soil moisture has not been limited or the crop has not been subject to waterlogging over winter, crop appearance at GS30 - 31 gives a reasonable indication of nitrogen reserves and the justification for nitrogen application at this stage. However, it is difficult to use visual appearance unless you have a benchmark, this has lead to the concept of the N rich strip.

N-Rich Strip concept and crop reflectance (NDVI – Normalised Difference Vegetative Index)

A useful guide that requires no sophisticated equipment is to apply to small areas of the paddock (size of a trial plot) an excess of nitrogen at sowing say 50 -100kg N/ha. During winter and spring by comparing crop vigour and greenness in these small N-rich areas with the rest of the crop an indication of N supply can be obtained.

Where there are large differences in crop appearance between the N-Rich strip and the crop it gives more confidence that nitrogen is required. With higher soil nitrogen supply it gives an opportunity to review application timing, possibly allowing a delay until later in stem elongation. For example, in 2007 two trials in Victoria (Inverleigh (HRZ) and Wimmera) with large soil N reserves (113kg N/ha 0-100cm and 176kg N/ha 0-90cm respectively) at planting, the optimum response to nitrogen was not obtained until at, or just before, flag leaf emergence, rather than earlier at GS30 - 31.

This visual difference can be quantified by using crop sensors that measure the reflectance from the crop canopy at particular wavelengths. Using these wavelengths, in particular red and near infrared, it has been possible to quantify canopy greenness using what is termed NDVI (Normalised Difference Vegetative Index – an index derived from an equation using both red and near infra red wavelengths). This gives an indication of both biomass present and the greenness of that biomass. This canopy sensing can be done remotely from aircraft/satellites or on a tractor mounted boom. In canopy management trials a hand held crop sensor had been used.
4. Planting date and planting rate

If all cereal seed rates are the same on-farm and no adjustment in calibration is made for seed size or planting date you have already lost control of the crop canopy!

The first management factor by which the grower can influence the crop canopy is through plant population. Matching tiller (shoot) numbers to plant population, as opposed to nitrogen application at seeding, is a much more successful way of gaining sufficient shoots for manipulation at stem elongation.

How many plants you target will depend on:
- **The sowing date** – earlier sowings require lower plant populations compared to later sowings as the tillering window is longer. So more tillers are produced per plant.
- **Region** – as a general guide drier regions sustain lower plant populations than wetter environments.

Overall, earlier planting provides greater opportunities to manipulate the crop canopy during the stem elongation period: the plant’s development is extended along with the earlier tillering period.

Use of crop calculators, monitoring tools and crop models to assist with canopy management

The movement of inputs such as fungicides and nitrogen from upfront at seeding to stem elongation provides huge opportunities to manage crops more successfully in terms of matching input to crop requirements. It also presents opportunities for a new range of grower support tools that could not have been employed when inputs were applied at seeding.

There a number of different tools and techniques that allow us to better manage our crops. From simple nitrogen budget calculators, soil water monitoring devices through to complete crop models that simulate the growth of the crop, such as the APSIM model (Yield Prophet®) and the New Zealand Sirius Wheat Calculator. These models help identify the numerous interactions that are taking place between the plant and its environment. Over the past three seasons some of the project canopy trials have been simultaneously run with Yield Prophet® in order to assess its ability to help the grower with canopy management. Results to date have been encouraging. The following two examples show the Yield Prophet® reports at the time of stem elongation and the resultant outcomes harvested 3-4 months later.

**Yield Prophet® on southern Victoria HRZ Canopy Management Trial 2007**

Yield Prophet® was run alongside these two wheat trials in order to ground truth the predictions against actual. The following excerpts from reports are limited to those made during the key growth stages for nitrogen application in the spring.

The following data displays the initial starting points for the APSIM predictions and the 1 August report specially commissioned for this GRDC project (SFS00015).

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>2 May</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling depth (m)</td>
<td>0.9</td>
</tr>
<tr>
<td>Initial plant available water (mm)</td>
<td>-19</td>
</tr>
<tr>
<td>Initial nitrate (kg ha⁻¹)</td>
<td>176</td>
</tr>
<tr>
<td>Organic carbon 0-10cm (%)</td>
<td>1.1</td>
</tr>
<tr>
<td>Rainfall since sampling (mm)</td>
<td>147</td>
</tr>
<tr>
<td>Sowing date</td>
<td>4 May</td>
</tr>
<tr>
<td>Variety</td>
<td>MacKellar®</td>
</tr>
<tr>
<td>Yield Prophet® forecast of GS30</td>
<td>16-25 Sept</td>
</tr>
<tr>
<td>Yield Prophet® forecast of GS37</td>
<td>2-15 Oct</td>
</tr>
</tbody>
</table>

Excerpt from 1 August 2007 APSIM Report - with starting details (above)

This site had very high levels of initial nitrate (nitrogen); however the high yield potential of the region has resulted in there being a 60% chance that the nitrogen treatments will out yield the control. There is a 40% chance that the 100kg ha⁻¹ treatment will out yield the 50kg ha⁻¹ treatment. It is possible that the in-crop treatments will out yield the pre-drill treatment by a small amount if the finish to the season is particularly favourable. It is unlikely that there will be a difference in yield between the 200 and 100 plants m⁻² treatments.

**Target plant populations for wheat** (based on project trials 2003 — 2006)

<table>
<thead>
<tr>
<th>100 plants/m²</th>
<th>150 plants/m²</th>
<th>200 plants/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drier environments</strong></td>
<td><strong>High Rainfall</strong></td>
<td><strong>High Rainfall</strong></td>
</tr>
<tr>
<td>– Mallee</td>
<td>- May sow</td>
<td>environment - June sow</td>
</tr>
</tbody>
</table>

N.B. All trials were conducted with complete ryegrass control. It maybe necessary to increase Mallee target populations in the presence of ryegrass.
So how did the predictions on 1 August compare to harvested yields?

**Graph 21**

Less than labelled rate

**Graph 26**

Rainfall (mm)

**Graph 24**

80

80

3.47

2x Folicur GS59

3.37

2% Stripe rust infection

**Graph 30**

Excerpt from 1 August 2007 APSIM report

At that stage there was a 40% chance that starting nitrogen in the soil there was 50kg N/ha and 100kg N/ha applied at seeding - model prediction 1 August.

(Invleighe) 2007 - GSR Apr - Nov 393 mm Influence of N timing and rate - Victorian HRZ

<table>
<thead>
<tr>
<th>Nitrogen Timing</th>
<th>LSD 0.37 t/ha (significant p&lt;0.001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero N</td>
<td>4.3</td>
</tr>
<tr>
<td>30 kg N/ha</td>
<td>4.5</td>
</tr>
<tr>
<td>60 kg N/ha</td>
<td>4.7</td>
</tr>
<tr>
<td>100 kg N/ha</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Graph 52**

Influence of N timing and rate in wheat - Wimmera 2007

<table>
<thead>
<tr>
<th>Nitrogen Timing</th>
<th>LSD 0.35 t/ha (significant p=0.001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero N</td>
<td>3.8</td>
</tr>
<tr>
<td>100 kg N/ha</td>
<td>3.5</td>
</tr>
</tbody>
</table>

**Excerpt from 3 September 2007 APSIM report for this trial:**

With only 12mm of rainfall in August whilst the probability of response to nitrogen application was down to 50%, overall yield potential was still around 3 t/ha. There was no value exceeding the 50kg N/ha dose at this stage. This report is of great interest since it coincided with the last application of nitrogen at GS33 in the trial (applied 9 September).

**Graph 56**

In the Wimmera it was less accurate in predicting the difference between nitrogen timings. Later N timings applied at 3rd node generated a yield response but at seeding, applications of N did not.

**Graph 45**

In the HRZ it was less accurate at correctly predicting growth stage (phenology). The predictions were slightly behind the actual growth stages recorded in the field, a factor that may have lead to slight overestimates of yield.

**Graph 41**

Use of crop models such as Yield Prophet® is an excellent decision support tool for assisting growers with canopy management during stem elongation (particularly nitrogen and fungicides).

**Key points:**

- Overall at the key decision stages for applied nitrogen (early August and early September) Yield Prophet® was reasonably accurate showing probable responses to applied nitrogen despite high soil nitrogen reserves at both sites.
- In the Wimmera it was less accurate in predicting the difference between nitrogen timings. Later N timings applied at 3rd node generated a yield response but at seeding, applications of N did not.
- In the HRZ it was less accurate at correctly predicting growth stage (phenology). The predictions were slightly behind the actual growth stages recorded in the field, a factor that may have lead to slight overestimates of yield.

**Yield Prophet® on Wimmera Canopy Management Trial 2007**

Excerpt from 1 August 2007 APSIM report for this trial:

On 1 August, when decisions were being made as to whether to toopress, the model predicted that despite the high starting nitrogen in the soil there was a 70% chance of applied N treatments out yielding the zero N control. It also predicted little difference due to nitrogen timing based on initial soil nitrogen levels. At that stage there was a 40% chance that 100kg N/ha would out yield 50kg N/ha. There was a 50% probability of the untreated crop yielding approximately 3.1 t/ha with approximately 1 t/ha advantage to nitrogen application at 50% probability.
Key points:

- Canopy management and tactical input use occur at seeding and during stem elongation – so growers need to know these growth stages.

- Adopting the correct planting population is the first most important step in providing the optimum number of shoots to manipulate at stem elongation.

- Extra shoots provided by plants are more strongly correlated to yield than extra shoots produced by increased nitrogen at seeding (project trials).

- Recognise that the biggest driver of the cereal crop canopy under Australian conditions is soil moisture - therefore make sure at stem elongation you know how your soil moisture levels compare with the previous spring, before nitrogen application.

- Knowledge of your soil nitrogen reserves kg N/ha (to the depth of the rooting zone for that crop) – helps nitrogen rate and timing window for application.
  - Higher soil nitrogen reserves – in general reduce N dose required and push timing later.
  - Lower soil nitrogen reserves – increase the need for small quantities of nitrogen for tiller production (20-30kg N/ha) at planting (see next section).

- Simple N-Rich and N free strips give useful visual indications of soil nitrogen supply.

- Earlier planting (May) gives longer development periods and greater opportunity to manage the crop canopy with in-crop input.

- Moving inputs (fungicide and nitrogen) application from upfront application to tactical in-crop application enables growers to use a far wider range of tools, techniques and models in order to harness the benefits of canopy management.

- Yield Prophet®, which uses the APSIM crop model, enables many of the complex interactions to be simulated and turned into yield probabilities. Provided the soil is well characterised these models can be an invaluable aid to canopy management.

- Alternatively make sure that at least soil nitrogen reserves and soil moisture are known.
A Tactical Nitrogen Strategy, what is it, when and where should it be used?

One of the key features of the focus on canopy management in cereals has been the adoption of a tactical nitrogen approach, where nitrogen has been delayed from seeding until the start of stem elongation (GS30 - 31). In the recent run of droughts this technique resulted in considerable fertiliser savings as growers took stock of the deteriorating season and did not apply nitrogen in the spring. Where rainfall is less limited has this technique been successful?


So how has a tactical nitrogen approach, based on stem elongation N, compared to a strategic approach using upfront nitrogen over the last three seasons?

2005

In many regions the 2005 season was characterised by a late break followed by a cool wet October.

Key points 2005:

- Across a wide range of environments the four wheat trials illustrated that nitrogen timed at early stem elongation (GS30 - 31) (tactical nitrogen) gave equal or superior yields to crops where upfront nitrogen was placed in the seedbed at sowing or pre sown.
- At those sites where nitrogen was delayed until flag leaf emerging (GS37) there were still significant increases in yield over the zero N treatments. It may be possible to adjust nitrogen strategy to take into account improved yield expectations later in stem elongation.
- Where there was no response to nitrogen due to spring drought and soil constraints (Mallee) there were more advantages to applying nitrogen at stem elongation than at seeding.
- When applying nitrogen in-crop at the start of stem elongation, applying N in advance of a rain front is more important than the exact growth stage. In-crop (although GS31 has been a target for application), the window can be broadened from late tillering GS25 - 31 to take advantage of rainfall.
2006

An extremely dry season throughout, though parts of southern WA still produced good yields.

The dry conditions resulted in trials in both the Mallee and the Wimmera failing to produce a grain yield. Yields from Hart, SA indicated no response to N and yields of approximately 0.5 t/ha (featured in section on row width).

Key points 2006:

- **Dry conditions resulted in low yields throughout much of the High Rainfall Zone.**
- **Under these conditions, soil moisture was the limiting factor, not nitrogen. Most trials showed no response to nitrogen applied.**
- **The 2006 season indicated a number of advantages using a tactical nitrogen approach even though delayed decision making due to the dry season resulted in a lack of response to nitrogen.**
- **In a season such as 2006 the “wait-and-see approach” of a tactical N application presented an opportunity to consider longer term weather indicators (for example, SOI – Southern Oscillation Index) and to make better use of crop models and crop observations. This information will assist in determining the level of soil nitrogen (tillering, greenness) before N application is made.**
- **Tactical N approach in 2006 meant many growers were able to save money on fertiliser expenditure.**
- **However if the crop is taken for hay production not grain, dry matter will be reduced relative to N at sowing treatments. (See later section on dry matter)**
- **Note where very low soil nitrogen is present at sowing (Liverpool Plains) and the irrigated crop was less moisture stressed, tactical N was unable to match yields of upfront N in a short season crop (5 months) see page 35-36.**

Drought affected wheat in southern Victoria 2006 (note strong edge effect in plots).
2007
An extremely promising start with good early opening rains followed by drought in spring, long season crops in some HRZ regions were saved by early November rain.

Key points 2007:

- Characterised by generally earlier plantings (due to the early break), the response to nitrogen tended to be greater with stem elongation timings rather than where emphasis was placed upfront.

- Where the influence of plant population was tested it was clear that in comparison to previous seasons in HRZ (that were later sown) the lower populations (80-100 plants/m²) were relatively higher yielding than in previous years. Wheat plant populations around 150 plants/m² appeared to be an excellent target for most situations.

- For the first time in Mallee project trials, low soil nitrogen and almost no spring rainfall resulted in no yield response to the GS31 or GS39 nitrogen. In the past with higher soil N reserves (over 80kg N/ha 0-60cm) this scenario has favoured GS31 N. In 2007 with lower reserves it did not. Absence of N uptake in spring was confirmed with grain proteins that were the same as the unfertilised controls.

- With an early break and early sowing and adequate soil moisture the yield response was greater to tactical N than upfront N.

Why would smaller canopies at the start of spring yield more than larger canopies?

In these trials similar yields were generated from totally different crop structures: where nitrogen was applied earlier, canopy size was greater earlier in the season, principally as a consequence of greater tiller numbers per m². Greater emphasis on nitrogen upfront created higher shoot numbers but at the same time higher shoot losses between GS31 and grain fill.

Influence of 100kg N/ha applied at different timings on crop structure at GS31 (tillers/m²) and during grain fill (ears/m²) – Wimmera, Victoria 2005.

A common request from advisers is to have specific tiller targets at GS30 - 31, in order to set up a particular yield expectation. In this work different tiller numbers per m² created by different nitrogen timings did not correlate to yield or final ear number (a result that is at odds with some of the trial work in WA, conducted by other groups).

Influence of moisture stress on larger crop canopies

As well as potentially setting up the wrong balance of shoots to individual grain sites, larger canopies use more water at earlier growth stages. This may not reduce yield if the crop can finish before water stress approaches wilting point. However trials in 2007 gave clear indications that ears produced from larger canopies (in the Wimmera and Liverpool Plains) showed more moisture stress than those from smaller canopies grown with later applied nitrogen.
Greater nitrogen efficiency

Moving nitrogen timing from the seedbed to early stem elongation has in some trials resulted in greater nitrogen efficiency, since the protein content of crops fertilised at these later timings have produced higher proteins and equal or greater yield.

The work shows that nitrogen applied at early stem elongation does not require high tiller numbers in order to create yield. Crops with lower tiller numbers compensate with the other two yield components (grains per ear and grain size).

Note this compensation will be sufficient provided enough shoots are supplied by the plant population and there is a soil nitrogen reserve to sustain them until stem elongation (as an approximate guide levels above 50kg N/ha in the top 60cm at planting).

Yield increases from stem elongation N are primarily due to increased grain sites per ear and to a lesser extent grain size. Tiller losses post stem elongation are greater where there is higher N applied pre GS31. This is probably because extra unnecessary canopy production (tillers) restrict the ability to compensate with more grain sites.

Green Area Index (GAI) and dry matter

Some specific sites revealed that the green area index (GAI – total surface area of greenness) in crops with tactical nitrogen is initially smaller than crops grown with upfront N. In most cases the GAI from tactical nitrogen application is greater than the GAI of an upfront N crop. In crops with low soil nitrogen reserves the improved GAI from stem elongation N occurs very late in grain fill. It is then too late to increase yield through grains/ear or grain size. GAI at flowering has, in some trials, been a good indicator of whether tactical nitrogen will be higher yielding than upfront alternatives.

Greater nitrogen efficiency

Moving nitrogen timing from the seedbed to early stem elongation has in some trials resulted in greater nitrogen efficiency, since the protein content of crops fertilised at these later timings have produced higher proteins and equal or greater yield.

Canopy management is about duration of crop canopy as well as total green area

Increasing grain yield from later nitrogen timing (with more grains per ear) has also been associated with increased crop canopy duration at sites with adequate soil moisture. This is indicating that stem elongation nitrogen may also better feed the crop through the later stages of grain fill provided it has the water available to it. This was apparent generally in 2005 and more specifically in southern Victoria in 2007.

The work shows that nitrogen applied at early stem elongation does not require high tiller numbers in order to create yield. Crops with lower tiller numbers compensate with the other two yield components (grains per ear and grain size).

Note this compensation will be sufficient provided enough shoots are supplied by the plant population and there is a soil nitrogen reserve to sustain them until stem elongation (as an approximate guide levels above 50kg N/ha in the top 60cm at planting).
When is a tactical nitrogen approach more or less likely to work?

With a tactical nitrogen approach:
- A smaller canopy is produced from autumn until early spring.
- Little upfront nitrogen is applied at seeding and instead the crop canopy is primarily fed from early stem elongation.
- Excess tiller formation is avoided and yield relies on compensation in terms of grains per head, individual grain weight and less tiller loss.
- Smaller crop canopies created by later fertiliser applications stay greener longer and because of higher grain protein content give a greater nitrogen efficiency.

From the work conducted over the last three seasons a number of key factors have emerged which influence the success of a tactical nitrogen approach.

**Influence of soil nitrogen level on success of tactical N**

Where no upfront nitrogen is applied, the crop is entirely dependent on the nitrogen in the soil to drive canopy growth through the seedling and tillering phase.

Where the soil nitrogen reserve in the top surface of the soil is low at sowing (below 50kg N/ha (0-60cm), the growth constraint on the crop canopy can be too great (in terms of tiller loss) for the crop to compensate sufficiently when N is applied at stem elongation. In many cases this constraint can be an advantage if the spring is very dry then the constrained canopy will be better equipped to cope with the dry conditions.

An excellent example of where tactical N was not successful was in a trial conducted in northern NSW in 2006, by (Agravac, NSW DPI, and FAR a GRDC Agribusiness extension project). In a short season scenario (five month crop duration) Ventura wheat showed a significant yield disadvantage to nitrogen timed during stem elongation (GS31 - 39) compared to the dose applied at seeding. Though the effect of a later seeding date was probably significant in this trial (see following section) the primary effect is likely to have been due to the low soil nitrogen reserves (25kg N/ha 0 – 90cm in the soil profile).

This low reserve significantly constrained canopy growth up to stem elongation (200 tillers/m² more where N was applied at seeding) in terms of dry matter, green area index and tiller number.

With the canopy benefiting from irrigation in the spring (123mm plus 111mm G5R) the potential of the additional shoots generated by nitrogen at seeding was realised whilst in the short growing season the later N was unable to compensate.

**Broad scenarios based on soil nitrogen level**

1. **If high soil N reserve (over 100kg N/ha 0-60cm)**
   - No N constraint on canopy at GS30 - 31
   - Advantage to tactical nitrogen as early growth driven by soil nitrogen reserves
   - Wet spring consider N application from pseudo stem erect up to booting GS30 - 45 dependent on crop status (colour) and rainfronts. For applications of nitrogen over 40-50kg N/ha consider splitting dose with 50-60% dose at GS30 - 31 and a second dose at flag leaf dependent on rainfall during stem elongation. – TACTICAL N OK.

2. **If moderate soil N reserve (50 -100kg N/ha 0-60cm)**
   - Little constraint on canopy until GS30 - 31
   - Early growth driven by soil nitrogen reserves but need for N application during stem elongation unless crop water stressed and outlook dry
   - Use any timing in the window from GS30 - 32 to apply nitrogen based on reliable rainfall events. If no rainfall, consider delaying until flag leaf. If no rain by flag leaf stage, consider whether application is needed.
   - TACTICAL N OK.

3. **If low soil N reserve (less than 50kg N/ha 0-60cm)**
   - Constrained canopy
   - Better equipped where dry conditions more prevalent in the spring
   - Consider small applications of N at seeding 20-40kg N/ha then tactical N at stem elongation.
   - TACTICAL N OK.

4. **If low soil N reserve (less than 50kg N/ha 0-60cm)**
   - Wet spring conditions more probable (or irrigation), inadequate crop canopy to harness the potential of the season even with stem elongation nitrogen or high water holding capacity and no rain fronts for uptake.
   - Disadvantage in entire N applied as tactical N
   - TACTICAL N NOT OK – CONSIDER UPFRONT N SPLIT with GS30 - 31
   - Tactial N will be less successful where root disease is present. In these cases it may also not be appropriate.
Tiller (canopy size) differences of this magnitude cannot be compensated for in a short season crop where water (by irrigation) is available in the spring. In a dryland scenario the extra tillers generated by nitrogen application could be a disadvantage.

Influence of sowing date on the success of tactical N

Though not investigated within the project, the following observations over the last three seasons should be taken into account.

Later sowing (after mid June) versus early sowing (May)

Sowing late naturally reduces the size of crop canopy since there are less leaves and less tillers. Canopy size is already limited by later sowing. In addition, later sowing speeds up development and gives less opportunity for compensation in grain size and number of grains per head. Later sowing also reduces accurate timing for in-crop application since stem elongation growth stages take place more quickly, occurring later in spring when conditions are warmer and drier. The benefits of sowing later are reduced when using a tactical nitrogen approach as the crop requires less overall nitrogen. Yield potential is limited in a short growing season.

Influence of cultivar on the success of tactical N

It is not only the sowing date that influences the length of growing season but cultivar choice. For the same sowing date longer season wheat (winter wheat) tends to spend more time in the tillering phase resulting in higher shoot numbers than shorter season wheat. There was evidence in 2005 and 2006 that greater emphasis on nitrogen upfront (50/50 split seedbed and GS31) compared to a later 50/50 split (GS31 and 39) was less detrimental in shorter season wheat (Chara®) than it was with longer season wheat (MacKellar®) for the same sowing date. Note that with earlier sowing in 24 May 2006 tactical N was either equal or better than strategic upfront N. In 2005 where the sowing date was later (9 June) there was no difference in yield between treatments.

How does row width interact with some of principles of canopy management?

Much of the work on canopy manipulation and tactical nitrogen timings has been carried out on a narrow row spacing (150 – 200mm) in the High Rainfall Zone. How do these management techniques work if cereal crops are sown in wider rows and in drier country?

This has not been a major study component of the project, however work conducted at Hart in South Australia and non-project work funded by Southern Farming Systems in the HRZ of Victoria has identified some interesting interactions between crop structure, yield and row spacing.

In non-project work on wheat, results have illustrated that moving to wider rows (200mm spacing 8° to 300mm spacing 12°) has reduced tiller numbers, final ear population and yield (by approximately 6%).
In this work there was no significant interaction between wider row spacing and nitrogen timing. There was a trend in one of the varieties tested that upfront nitrogen might be more effective in wider rows.

In trials in drier environments of South Australia (Hart Field Day site), it has not been possible to address the issue of nitrogen timing interactions with row spacing. Over the last two years there has been either no or very little response to nitrogen.

In 2006 wider row spacing (row spacings 350mm (14") produced significantly inferior yields (approximately 0.1 t/ha) to narrow spacing (175mm (7"), although all yields were below 1 t/ha.

In 2007 the narrow row spacing (mean of N timing and plant population) produced a higher grain yield (0.07t/ha) compared to the wider row spacing. There was an interaction between row spacing and plant population since there was no difference in yield due to row spacing at a lower plant population (90-100 plants/m²), but wider rows were lower yielding at the higher population (170-180 plants/m²).

Key points:

- Increasing row spacing can have many advantages for the whole farming system, in terms of residue flow at sowing, inter-row planting and weed control, however it has been associated with small yield reductions in both the HRZ and in the drier environments.

- When moving to wider row spacing the competition within the row between plants can lead to a reduction in tillers per plant and tillers per unit area compared to narrow row spacing.

- Limited results to date suggest that increasing plant population in order to compensate for less tillers/m² will increase competition. So when moving to wider rows it may be appropriate to reduce the plant population to lessen inter plant competition within the row.

- At present it has not been possible to determine whether wider row spacing makes tactical (GS30 - 31) nitrogen more or less applicable, it is clear that there may not be the same flexibility to adjust the crop canopy by increasing the plant population in wide rows.

- Where higher populations are required in wider rows, planting seeds in a band (as opposed to row) is an obvious way to remove some of the interplant competition; however this inevitably disturbs more soil than planting in a narrow row and may result in greater weed seed germination.
4. Interactions between Canopy Management and Disease Control in Cereals

Fungicides as Canopy Management tools
The principal effect of a fungicide on a plant under disease pressure is to increase the green leaf retention, particularly during grain fill. Therefore fungicides both maintain green area index GAI (the total green surface area of crop occupying one square metre of ground) and canopy duration, two factors key to the practice of canopy management.

How does nitrogen application influence the need for disease control?
Nitrogen application is a key tool by which the grower influences canopy size and duration, more nitrogen increases canopy size and if water is available increases canopy duration. But how does this influence the need for disease control in susceptible cereal varieties? If increased nitrogen rate creates a bigger canopy does this result in a greater need for disease control? Data from the project clearly shows that there is a relationship between nitrogen application and subsequent disease pressure under long season conditions.

What is the influence of nitrogen timing on disease?
One of the major effects of canopy management in Australia has been a move to the use of tactical nitrogen application, where the nitrogen application to the crop is delayed until early stem elongation. Crops grown using nitrogen at these delayed timings are thinner but stay greener longer compared to upfront nitrogen. But how does that influence the need for disease control?
Fungicides as Canopy Management tools

The principle effect of a fungicide on a plant under disease pressure is to increase the green leaf retention (GLR), particularly during grain fill. Therefore fungicides both maintain green area index (GAI) and canopy duration, two factors key to the practice of canopy management. Fungicides maintain greenness in the canopy.

Fungicides are not usually thought of as canopy management tools since they tend to be linked to a disease control. However the principal yield effect of a fungicide relates to its ability to keep the crop greener for longer, particularly during grain fill. The correlation between green leaf retention through fungicide treatment and resultant yield is strongest when the crop is at the flowering or grain fill stage. In some trials where different fungicide products and rates are tested, the correlations reveal just how closely linked yield is with green leaf retention. In barley this correlation is usually strongest with flag-1 (the leaf below flag leaf) since the flag leaf is small and much less significant. In WA work conducted in 2006 showed the correlation between fungicide performance in terms of green leaf retention and yield was very strong \( r^2 = 0.93 \) on flag-1 and \( r^2 = 0.81 \) on flag-2 when assessed at the end of flowering.

In wheat the correlations between GLR/GAI and yield tend to be more associated with the flag leaf but flag-1 is also important. Plotting green leaf retention over time enables the grower to see just how clearly fungicide impacts on green leaf area and duration of the crop canopy.

The correlation between GLR and yield is weaker at earlier growth stages. This situation frequently relates to lack of water availability later in grain fill. That is, the fungicide creates differences in green leaf retention but these are curtailed by lack of soil moisture to express the difference.

The probability of a yield response to a fungicide strongly relates to:
1. The level of disease in the crop – greater cultivar resistance less response.
2. The earliness of infection.
3. The differences in green leaf retention due to fungicide application, regional rainfall post flowering or available soil moisture.

Soil water availability is a key factor in yield enhancement through strategic fungicide use. Therefore any available soil moisture (and therefore crop canopy GAI) during flowering and grain fill will influence the probability of a response to fungicide applied at stem elongation.

Factors influencing soil moisture and fungicide response include:
- Historical low yields on the farm or in a region (less than 2.5 t/ha) immediately tell the grower that grain fill conditions do not favour a response to fungicide application. The principal exceptions are where severe disease infects the crop early at stem elongation or where stem rust becomes a threat.
- Historical regional rainfall post fungicide application at G339 - 49 (in WA yellow spot responses have been linked to the probability of rainfall post flag leaf). What are the rainfall probability figures for the region? This knowledge may determine whether a full dose or reduced dose of fungicide is applied.
- What is the water holding capacity of your soil. If the soils hold little water then it will be the regional rainfall stats that are the principal drivers.
Key points:

- Fungicides are canopy management tools that influence green area index (GAI) and crop canopy duration, creating yield response through crop greenness, particularly during grain fill.
- The correlation between green leaf retention and potential yield is strongest if the fungicide effects can be expressed during flowering and grain fill.
- A grower should attempt to match fungicide expenditure with both disease expression and adequate soil moisture for extra GLA to be expressed as yield.
- Regional rainfall, soil water holding capacity (and associated subsoil constraints) will determine whether the green leaf area differences due to disease/fungicide application will be expressed as a yield benefit.
- Historic low yield potential (less than 3 t/ha) means that opportunities for fungicides to create green leaf differences post flowering are unlikely.
- The two exceptions are where disease infection is earlier than flag leaf emergence that is, at the start of stem elongation (GS30 - 32) or where the disease is stem rust. Note infection pre GS30 is more difficult to correlate to yield, since leaves present are less important to final yield.

How does nitrogen application influence the need for disease control?

Nitrogen application is a key tool by which the grower can influence canopy size and duration. The more nitrogen applied increases canopy size and if water is available increases canopy duration. But how does this influence the need for disease control in susceptible cereal varieties? If increased nitrogen creates a bigger canopy does this result in a greater need for disease control? Data from the project clearly shows that there is a relationship between nitrogen application and subsequent disease pressure.

To examine this interaction it was important to secure crop conditions where a nitrogen response was likely to occur. This research was undertaken over three years in Tasmania on the variety Mackellar® (2005 dryland and 2006 and 2007 irrigation). In all three seasons of the trial the crop was subject to leaf rust (Puccinia recondita) infection which progressed steadily from flag leaf emergence onwards.

To define the interaction, five levels of nitrogen were applied to the crop as a single dose at first node (GS31). Superimposed on these different nitrogen levels were 3 different fungicide regimes, a triazole based two spray program timed at GS32 and GS39 - 45 (Opus® 250 ml/ha), a triazole (Opus® 250 ml/ha) plus strobilurin (pyraclostrobin) based 2 spray program and no fungicide.

The work showed a significant interaction between managing the canopy for disease and the use of applied nitrogen in all three years of Tasmanian trials:

- It clearly illustrated that as nitrogen levels increased so did the level of leaf rust infection present in the crop canopy in the untreated crop.
- The differences in disease were more pronounced as the crop canopy reached the grain fill stage.
- The differences in disease occurrence due to applied nitrogen were not apparent when the two fungicide strategies were applied.

Greater nitrogen input where soil water is available leads to prolonged canopy duration. Increasing the nitrogen rate will lead to greater crop canopy greenness during flowering and grain fill. However this is only expressed if the crop is free from disease. If a susceptible crop is not protected then the increased nitrogen input increases the severity of the disease leading to a reduction in crop canopy retention.

Over the three seasons the differences in disease levels resulted in the optimum nitrogen level being 60kg N/ha where no fungicide was applied and double that where fungicide was used (120kg N/ha).
Disease Management and Crop Canopies – what are the interactions?

**Wheat**

Influence of fungicide application on optimum nitrogen rate - cv Mackellar®, Tasmania 2005 - 2007

- All three trial results were similar to the three year mean.

**Barley**

In barley trials on the mainland in 2006 and 2007 a complete absence of disease lead to no interaction between applied nitrogen and disease control. In non-project trials set down in 2004 and 2005 there was evidence that both scald and leaf rust in barley generated similar interactions between applied nitrogen and disease pressure.

Key points:

- In disease susceptible varieties, increasing nitrogen input where there is already disease present can increase disease pressure.
- The difference in disease pressure due to applied nitrogen has been noted in project and non-project trials conducted in the HRZ, it has not been noted in project trials in drier environments outside HRZ.
- The relationship has been noted in stripe and leaf rust in wheat as well as scald and leaf rust in barley.
- Increases in disease pressure due to increased applied nitrogen have resulted in significant yield interactions between the amount of nitrogen fertilizer and the fungicide applied.
- Work in Tasmania on high yielding red wheat (cv Mackellar®), showed that where fungicides were not used the nitrogen inputs for wheat were halved.

Therefore with susceptible wheats and barleys grown in long season HRZ environments – more nitrogen applied led to more disease and greater need for fungicide protection in order to secure the benefits of higher N applications.

**Influence of nitrogen rate and fungicide strategy on scald infection GS58S - cv Gairdner®, Southern Victoria 2004**

Based on 2 spray applications applied at GS30 and GS49. Strobilurin based on azoxystrobin.
What is the influence of nitrogen timing on disease?

One of the major effects of canopy management in Australia has been a move to tactical nitrogen application, where the nitrogen applied to the crop is delayed until early stem elongation. Crops with nitrogen applied at later timings are thinner but stay greener longer compared to upfront nitrogen. But how does that influence the need for disease control?

A key aspect of canopy management revolves around disease management. Fungicides are canopy management tools that influence both canopy size (the overall green surface area of the crop) and duration of the canopy (how long it stays green). If, through canopy management, the grower creates smaller canopies earlier or canopies that might stay greener for longer then it is likely that there could be an interaction with disease when susceptible varieties are grown.

If the use of tactical nitrogen (delayed until stem elongation) makes the crop canopy smaller there are a number of questions that need to be addressed:

• Will less nitrogen upfront reduce disease pressure?
• Will a smaller crop canopy be more vulnerable to any increased loss of green surface area?
• Does later nitrogen require more disease cover later in the season?

The dry seasons in 2006 and 2007 have limited the ability of the project team to look at these interactions, as trials were located in the eastern states, in particular Victoria.

Limited trial data indicates that nitrogen timing has interacted with fungicide timing to produce differential disease pressure. Differences are small, but the interaction has been significant (p=0.05) on some of the leaves assessed. Research with stripe rust susceptible varieties (Southern Victoria 2005) indicated a tactical N approach did not reduce disease incidence or the need for fungicide control. Disease incidence on flag-1 was highest in the tactical N treatment. Part of the reason for this may be greater green leaf retention lower in the crop canopy where tactical N nitrogen was used.

At the same trial site, work on Mackellar® indicated a similar pattern of treatment response with low levels of leaf rust infection. It was noted that green leaf retention improved with late nitrogen application, presumably giving better conditions for rust infection.

The yield results from these trials, whilst supporting conclusions presented in section 2, did not show an interaction between nitrogen timing and fungicide strategy employed. There was evidence of greater rust pressure where later applied nitrogen was used.
Disease Management and Crop Canopies – what are the interactions?

Results in 2007 on the susceptible variety Chara did not show an interaction between nitrogen timing and disease management in terms of yield, however there was an indication that the application of nitrogen itself increased disease pressure.

Work on barley in the Wimmera and in southern Victoria has not been subject to sufficient disease pressure in order to examine this interaction.

Key points:

- The influence of nitrogen timing on disease pressure has not been noted in project trials to the same extent as the impact of nitrogen rate.

- Limited data in susceptible wheat cultivars has suggested that crop canopies fertilised with nitrogen at stem elongation (GS30 - 39) are no less susceptible to disease.

- There was limited data to suggest that greater green leaf retention at stem elongation from nitrogen application created more disease pressure during grain fill.

- Interactions between disease pressure and nitrogen timing in these trials are limited to stripe and leaf rust in wheat.

- There has been insufficient disease in barley to determine any interactions in the course of the project in the eastern states trials.

Stripe rust in Mackellar (Tasmania).
Trial site locations for GRDC project SFS00015

- Young, NSW
- Birchip (Mallee), Vic
- Lubeck (Wimmera), Vic
- Naracoorte, SA
- Inverleigh, Vic
- North Midland, Tasmania
- Yorke Peninsula, SA
- South Stirling, WA
- Munglinup, WA
- Scaddon, Liverpool Plains, NSW