Cereal Growth Stages

GRDC
Grains Research & Development Corporation

THE LINK TO CROP MANAGEMENT

Introduction

This guide has been produced as part of the GRDC funded project (SFS 00006) examining the role of disease control and canopy management in optimising cereal production in south east Australia. Results are primarily based on information generated in the high rainfall zone in 2003 and 2004, though control sites in the Mallee and Wimmera provided drier environments for comparative data.

The booklet is designed to give growers greater confidence in identifying the important cereal growth stages and how they relate to the principles of disease management and canopy management. The booklet is split into three distinct but related sections:

Contents

The main emphasis of this booklet is on wheat, but where possible, strategy comments have been contrasted with barley. In addition, in the disease management section, the principal focus is the use of foliar fungicides since these products were the principal products tested in the project. It should be emphasised that fungicides represent the last line of defence against disease after other measures such as stubble management, seed hygiene, crop rotation and cultivar resistance have been considered.

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1. Cereal Growth Stages

Why are they 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, plant growth regulator, fungicides & 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 in relation to disease control and canopy management

The principal Zadoks growth stages used in relation to disease control and nitrogen management are those from the start of stem elongation through to early flowering: Zadoks GS30 – GS61.

Early stem elongation GS30-33 (pseudo stem erect – third node on the main stem)

This period is important for both nitrogen timing and protection of key leaves. 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.

Leaf dissection at GS32 & GS33

This is a method for determining which leaves are emerging from the main stem prior to the emergence of the flag leaf. Knowing which leaves are present is critical if fungicide use is to be optimised to protect leaves.

1. Cereal Growth Stages

Why are they important to cereal growers?

A growth stage key provides a common reference for describing the crop's development, so that we can implement agronomic decisions based on a common understanding of which stage the crop has reached.

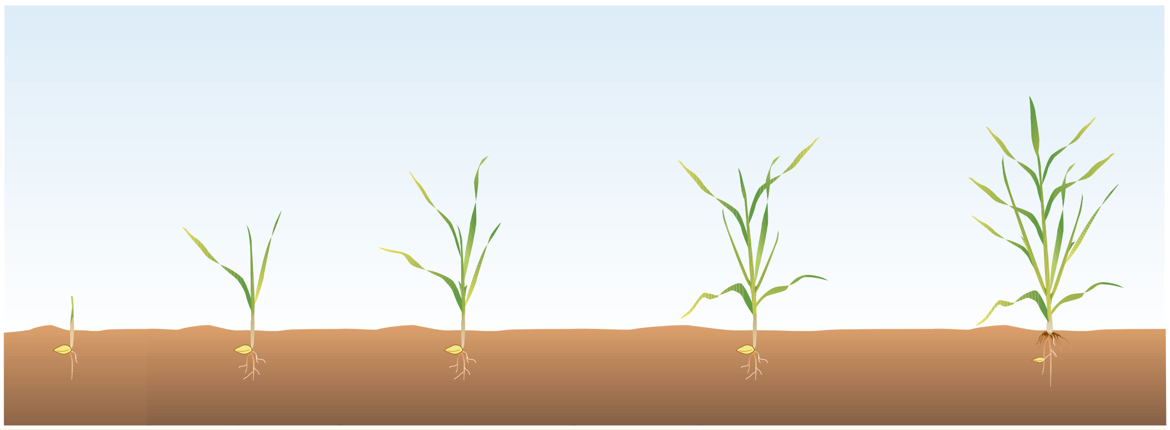
Zadoks Cereal Growth Stage

The most commonly used growth stage key for cereals is the:

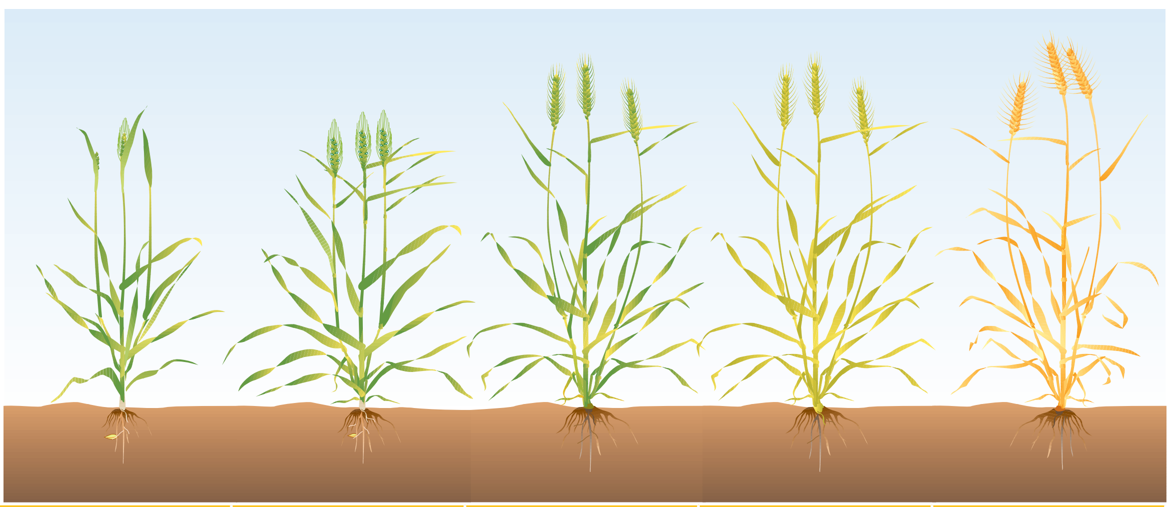
- Zadoks Decimal Code, which splits the development of a cereal plant into 10 distinct phases of development and 100 individual growth stages.
- It allows the plant to be accurately described at every stage in its life cycle by a precise numbered growth stage (denoted with the prefix GS or Z e.g. GS39 or Z39)

Within each of the 10 development phases there are 10 individual growth stages, for example, in the seedling stage:

GS11	Describes the first fully unfolded leaf
GS12	Describes 2 fully unfolded leaves
GS13	Describes 3 fully unfolded leaves
GS19	Describes 9 or more fully unfolded leaves on the main stem



Zadoks Growth Stage	GS 00 - 09	GS10 - 19	GS20 - 29	GS30 - 39	GS40 - 49
Development phase	Germination	Seedling growth	Tillering	Stem elongation	Booting



Zadoks Growth Stage	GS 50 - 59	GS60 - 69	GS70 - 79	GS80 - 89	GS90 - 99
Development phase	Ear emergence	Flowering	Milk Development (grain fill period)	Dough Development (grain fill period)	Ripening

GS07 – Germinating seed with root (which forms first) and shoot

GS 11 – 1st unfolded leaf (deep sown on left, correctly sown on right)

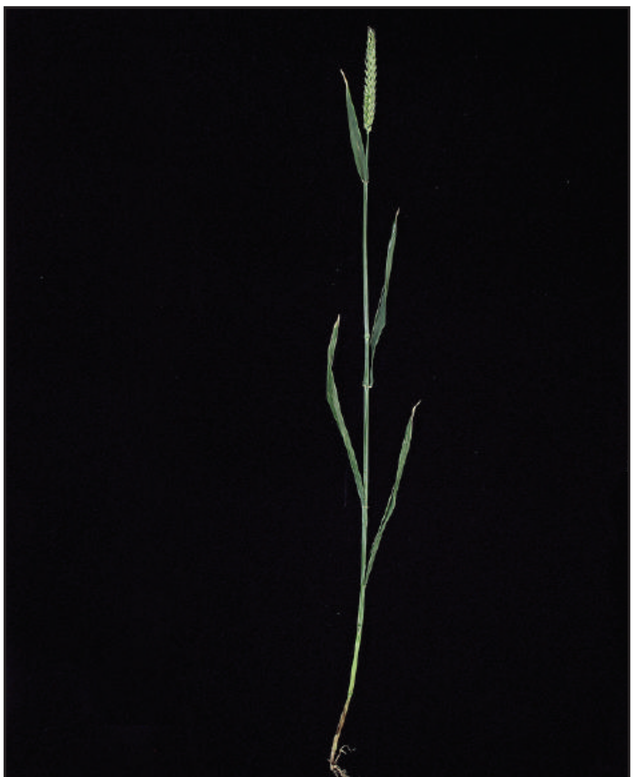
GS13 - 3 unfolded leaves with first tiller emerging from first leaf axial

GS24 – Main stem and 4 tillers (note appears to be 3 tillers, however very small tiller on right)

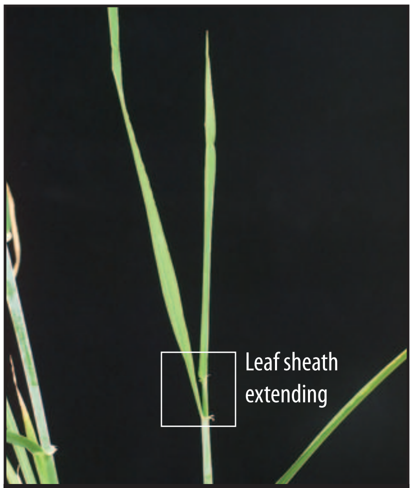
GS30 – Start of stem elongation (note leaf sheath extending)

GS32 – Second node formed in main stem (approximates to leaf 3 emergence or Flag -2 or third last leaf)

GS39 – Flag leaf emergence (emergence of the most important leaf in wheat)



GS59+ Ear emergence complete (flowering apparent)



GS43 – Start of the booting phase - Flag leaf (leaf sheath extending)

GS49 End of booting – leaf sheath splitting open (for awned wheats and barley 1st awns emerging)

GS55 Ear 50% emerged on the main stem

GS65 – Mid Flowering (pollen sacs visible on outside of glumes)

GS71 – Start of grain fill – forming grain watery ripe

GS87 – Hard dough stage towards end of grain fill H45 fungicide treated on right, untreated on left

Key Points

- The Zadoks Growth Stage key does not run chronologically from GS00 to 99, for example when the crop reaches 3 fully unfolded leaves (GS13) it begins to tiller (GS20), before it has completed 4, 5, 6 fully unfolded leaves (GS14, 15, 16).
- It is easier to assess main stem and number of tillers than it is the number of leaves (due to leaf senescence) during tillering. The plant growth stage is determined by main stem and number of tillers per plant e.g. GS22 is main stem plus 2 tillers up to GS29 main stem plus 9 or more tillers.
- In Australian cereal crops plants rarely reach GS29 before the main stem starts to stem elongate (GS30).
- As a consequence of growth stages overlapping it is possible to describe a plant with several growth stages at the same point in time. For example a cereal plant at GS32 (2nd node on the main stem) with 3 tillers and 7 leaves on the main stem would be at GS32, 23, 17, yet practically would be regarded as GS32, since this describes the most advanced stage of development.
- Note: after stem elongation (GS30) the growth stage describes the stage of the main stem, it is not an average of all the tillers. This is particularly important with fungicide timing e.g. GS39 is full flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged.

Key growth stages in relation to disease control and canopy management

The key growth stages for both disease control and canopy management in cereals are those covered by the period from GS30 (the start of stem elongation) to GS61 (start of flowering). These growth stages are particularly important for management decisions related to canopy management and disease control and will be referred to several times in this booklet.

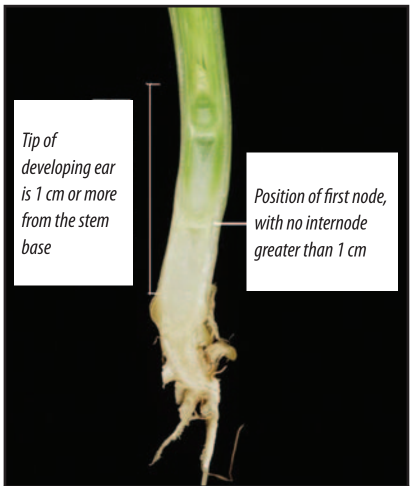
Development Phase	Decimal Growth Stage	Description
Stem Elongation GS30 - 39	GS30	Pseudo stem erect (Embryo ear at 1cm) – start of stem elongation
	GS31	1st node on main stem
	GS32	2nd node on main stem – leaf 3 emerges on main stem – 2 leaves below the flag leaf this is referred to as Flag-2 or F-2
	GS33	3rd node on main stem – leaf 2 (F-1) emerges on main stem
	GS37	Flag leaf just visible on main stem
	GS39	Flag leaf fully emerged on main stem with ligule showing
Booting GS40 - 49	GS41	Flag leaf – leaf sheath extending
	GS45	Mid boot – ear swelling in top of main stem
	GS49	1st awns emerging (barley/awned wheat)
Ear emergence GS50 -59	GS59	Ear fully emerged on main stem
Flowering GS60 - 69	GS61	Start of flowering on main stem (approx 1/3 of the way up the ear)

Early stem elongation GS30-33 (pseudo stem erect – third node on the main stem)

The start of stem elongation is particularly important for decisions on fungicide and nitrogen inputs, since it marks the emergence of the first of the important yield contributing leaves and the point at which nitrogen uptake in the plant increases strongly. In order to correctly identify these growth stages more precisely, main stems of the cereal plants are cut longitudinally and the position of nodes (joints in the stem) and the length of internodes (cavity in the stem between nodes) measured with a ruler.

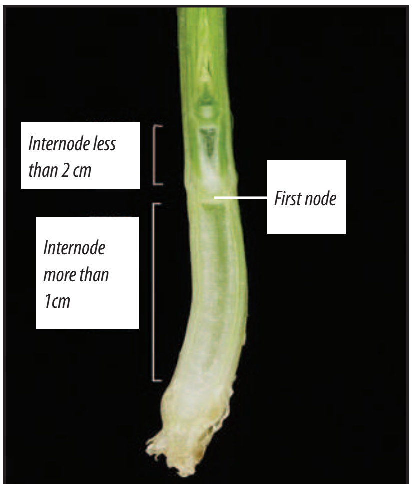
Dimensions defining stem elongation with internal stem base dimensions.

Preparation of main stem for measurement

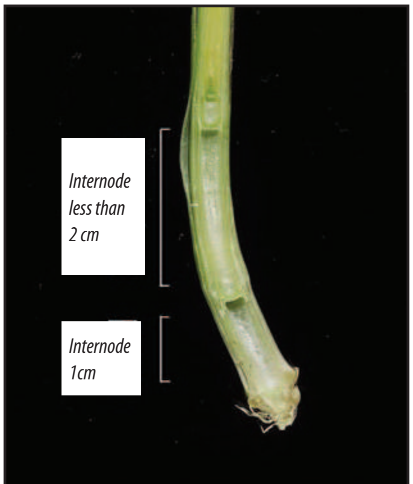


GS30 - Main stem with embryo ear at 1cm

GS30 The tip of the developing ear is 1 cm or more from the base of the stem where the lowest leaves attach to the shoot apex.



GS31 – Early 1st node formation



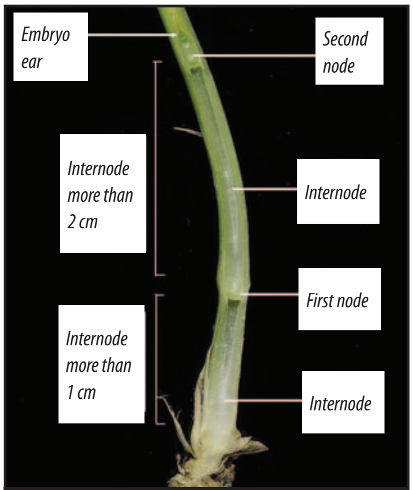
GS31 – 2nd node still has less than 2cm from 1st node

GS31 The first node can be seen 1 cm or more above the base of the shoot (with clear internode space below it) and the internode above it is less than 2 cm.

Growth Stages

GS32 The second node can be detected and the internode below it exceeds 2 cm, however the internode space above the node has not yet reached 2cm

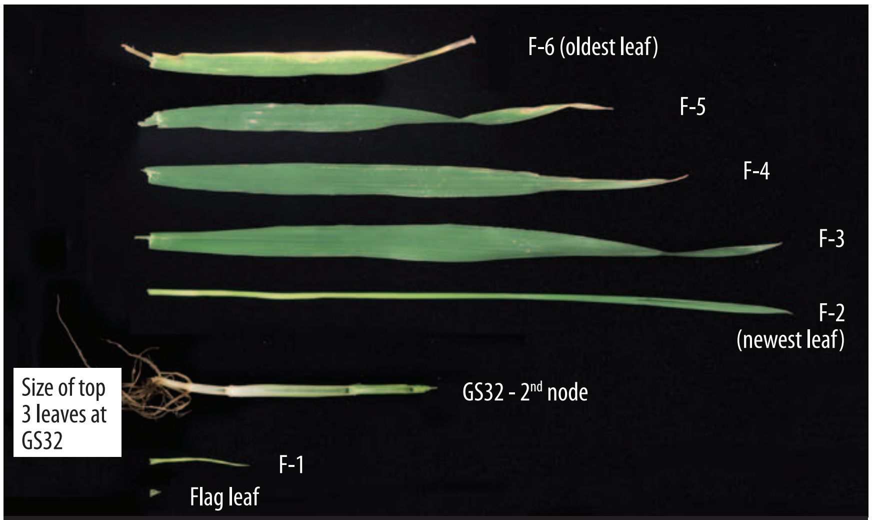
Third node (GS33) and all subsequent nodes e.g. GS34, GS35 and GS36 are defined in the same way as GS32 the node has to have a clear 2cm space of internode space below it before it is distinguished as the next nodal growth stage.



GS32 – 2nd node formation

Leaf dissection from GS32

Identifying the most important leaves (top 3 leaves) before the emergence of the final flag leaf can be done with reference to the nodal growth stage (see disease management). However to be certain it is possible to dissect the un-emerged leaves from second node (GS32) onwards. Before GS32 the leaves yet to emerge are generally too small to properly identify. Note how small the flag leaf is at GS32.



GS32 - Dissection of the main stem leaves and nodes up to the embryo ear – note the small size of the flag leaf and leaf 2 at GS32

Key Points

- Use a ruler to measure node movement in the main stem to define early stem elongation growth stages.
- Take care not to confuse the basal node at the stem base with the first true node. Basal nodes are usually signified by a constriction of the stem below the node with an incompletely formed internode space, it is the point where the lowest leaves attach to the stem. Further, basal nodes will often grow small root tips. This is not the first node.
- Nodal growth stage can give an approximate guide to which leaf is emerging from the main stem, this can save time with leaf dissection when it comes to making decisions on fungicide application pre flag leaf (when all leaves are emerged).
- The rate of development influences the time between growth stages – later sowings spend less time in each development phase including grain fill, hence potentially have lower yield.
- Though it will vary between varieties and regions (due to temperature), during stem elongation leaves emerge approximately 5 – 10 days apart (10 under cooler temperatures at the start of stem elongation and nearer 5-7 days as the flag comes out.)
- The period of time between leaf emergences is referred to as the phyllochron and is approximately 100-120 (°C days), though it can be longer or shorter depending on variety. Barley varieties tend to have shorter phyllochrons, so leaves tend to emerge quicker.

2. Canopy Management in Cereals

What is Canopy management?

Canopy Management is managing the green surface area of the crop canopy in order to optimise crop yield and inputs.

How can growers practice canopy management?

Adopting canopy management principles and avoiding excessively vegetative crops may enable us to ensure a better match of canopy size with yield potential as defined by the water available.

Influence of plant population

Other than sowing date, plant population is the first point at which the grower can influence the size and duration of the crop canopy.

Influence of nitrogen timing and rate

Earlier timed "upfront" nitrogen increases tiller numbers and in many cases final ear number – but does it equal more yield? The results from this project would suggest no.

What is canopy management?

The theory

"Canopy Management" is attracting increasing attention and means managing the green surface area of the crop canopy in order to optimise crop yield and inputs. It is based on the premise that the crop's canopy size and duration determines the crop's photosynthetic capacity and therefore its overall grain productivity.

What has been its effect where adopted?

Where this management system has been developed (principally in Europe and New Zealand) it has shifted grower focus from lush, thick crop canopies to thinner, more open, canopies. At its simplest, the technique could be represented by a simple comparison of crop canopies.

Overseas growers practicing canopy management have target canopy sizes for specific growth stages, and nitrogen management is tailored to adjust the crop to these targets. If the canopy is too thin, nitrogen timing is brought forward, if it is too thick nitrogen timing is delayed.

Much of the change brought about by canopy management has been due to the adoption of lower plant populations and a greater proportion of nitrogen being applied later in the season.

Thinner Crop Canopy
Yield 6.18 t/ha & 12.0% Protein

Thicker Crop Canopy
Yield 6.20 t/ha & 10.6% Protein

Kellalac wheat sown 11th June Gnarwarre (Geelong region), Victoria (in high rainfall zone) region treated with same level of nitrogen

The question is: would this approach work in Australia*, where variable rainfall and hostile soils can work against the efficiency of post emergence applications of nitrogen?*

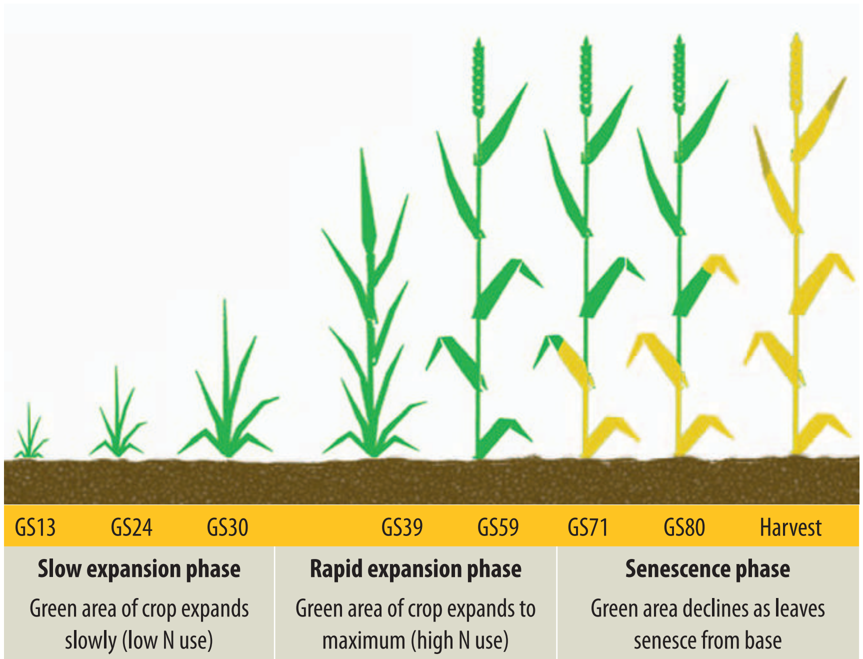
GRDC project (SFS 00006) run in southeast Australia, addressed this issue.

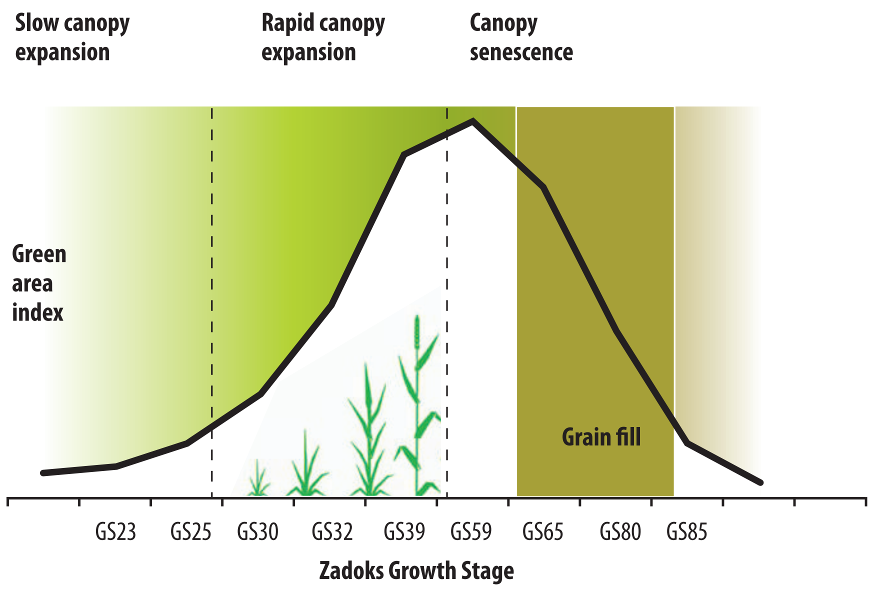
Crop canopy expansion and its measurement

The cereal crop canopy starts to expand at crop emergence and stops at ear emergence. There are three distinct phases that can be used to describe the life of the cereal crop canopy: the slow expansion phase, rapid expansion phase and the senescence phase.

- **Slow expansion phase**- crop emergence to the start of stem elongation or Growth Stage 30 (GS30). This phase has a low demand for nitrogen
- **Rapid expansion phase**- in this phase the crop canopy is expanding at its quickest and has the highest requirement for nitrogen. Cereal crop canopies are usually largest at ear emergence or Growth Stage 59 (GS59).
- **Senescence phase**- at first during flowering this phase is slow and then as grain fill progresses it becomes more rapid. It also marks a significant redistribution phase of the plant's life, as nitrogen is moved from the foliage to the grain and water-soluble carbohydrate (WSC) from the stem to the grain.

Canopy expansion in relation to growth





How is canopy expansion measured?

How the green surface area of the crop first expands, reaches it peak and then declines can be described in terms of the green area index – GAI and can be depicted by a graph.

Green Area Index GAI = the ratio between total green area of crop (one side of leaves) plus stem area, to the area of equivalent ground planted. Thus if the green area of the crop that stood on 1 square metre was 5m^2, the crop would be described as GAI 5.

The canopy at any growth stage can be assessed in terms of Green Area Index (GAI).

What do different sized crop canopies look like if they are difficult to measure?

Whilst growers cannot quickly measure GAI it can be estimated subjectively. The following pictures show different wheat crop canopies at maximum expansion (early ear emergence GS55 – early flowering GS61) varying from a GAI 1 to GAI 8. All photos were taken from project trials in south east Australia (note the relationship between GAI and the soil that is visible).

The aim of canopy management is to manipulate the green area index (GAI) in order to:

- Maximise the duration of the canopy during grain fill.
- Avoid overly thick vegetative canopies that are inefficient with both sunlight, water and nitrogen.
- Avoid excessively thin canopies that can be wasteful of sunlight and not fully utilise the water available.

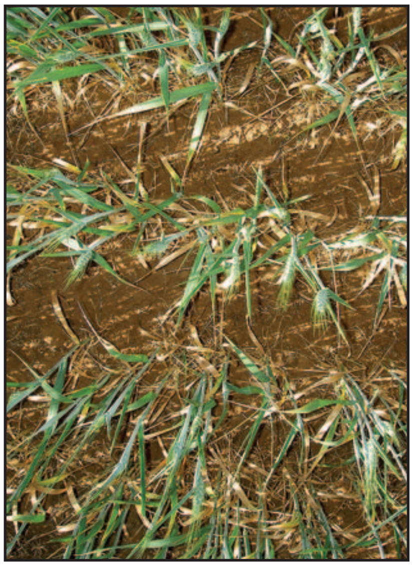
Thus the approach is not purely aiming for the optimum canopy size for the resources available, it is also using inputs to maintain the life of the crop canopy, particularly during grain fill.

So what inputs can be used to maintain the crop canopy during grain fill?

Fungicides - If cereal crops are under disease pressure fungicides act by maintaining the green area of the canopy.

Later nitrogen – applications of nitrogen at late stem elongation GS37-59 can result in greater green leaf retention during grain fill.

However, if part of the aim is to extend the life of the crop canopy during grain fill, will this concept work in Australia where canopy green leaf retention during grain fill is so frequently influenced by high temperatures and lack of soil water even in the high rainfall zone (HRZ)?



GAI 1 – Birchip (Mallee) cv Yipti 2004

GAI 3 – Birchip cv Yipti 2003

GAI 6 – Gnarwarre (HRZ) cv Kellalac

GAI 8 – Gnarwarre (HRZ) cv Kellalac

How can growers practice canopy management?

There are several factors that influence the size and duration of cereal crop canopies, unfortunately the most important is not under our control: available soil water. Soil water affects not only canopy size but, more importantly, canopy duration during grain fill. Therefore what is the relevance of a technique such as canopy management in Australia?

Adopting canopy management principles and avoiding excessively vegetative crops may enable us to ensure a better match of canopy size with yield potential as defined by the water available.

Canopy management is about managing inputs to match canopy size with available water to maximise grain yield and quality.

Soil Water Availability

Limited	⟷	Full profile
Require small canopies	⟷	Require larger canopies

So what inputs enable us to manipulate canopy size?

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

Larger/thicker canopies		**Smaller/thinner canopies**
Higher seedrates	⟷	Lower seedrates
More nitrogen	⟷	Less nitrogen
Earlier nitrogen	⟷	Later nitrogen (longer duration)
Early sowing	⟷	Later sowing
First wheats		Second wheats
Irrigated		Dryland
Longer season cultivars		Short season cultivars
Higher GAI	⟷	**Lower GAI**

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

Canopy management – Influence of plant population

Other than sowing date, this is the first point at which the grower can influence the size and duration of the crop canopy. Though optimum plant population varies with growing season rainfall, it is important to target a specific planting density.

Invariably higher plant populations create larger canopies earlier in the season. This frequently results in larger canopies overall. In the high rainfall zone higher plant populations can be useful with later sowings where sunlight can be wasted on thin crops. However with earlier sowings excessively thick canopies increase the risk of disease and lodging, creating poor quality grain, particularly with barley.

So what are the optimum plant populations for cereals?

Though the project examined seeding rates, there is already a large amount of published data on the subject, which may differ between regions. An example is shown in the table following.

Plant establishment densities according to cereal crop types (plants/m²)

	Average Rainfall (mm)		
	250-350	350-450	450-550
Crop	**Planting population (plants/m²)**		
Wheat	140-160	160-180	160-180
Barley	120-140	140-160	160-180
Oats	130-150	150-180	180-200
Triticale	160-180	180-200	200-220

Source: Crop Monitoring Guide (Victoria) – Top Crop Australia (Incitec/GRDC)

Project trials (sown May/early June) correlated reasonably well with these Top Crop guidelines in that there was relatively small yield effect from plant populations in the range 100 – 200 plants/m².

Gnarwarre rainfall 2003 = (GSR 340mm)

Birchip rainfall 2003 = (GSR 213mm)

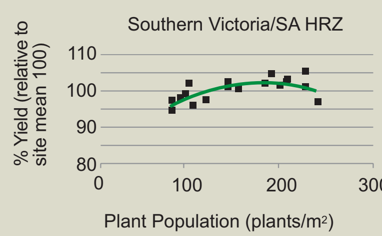
Hamilton rainfall 2003 = (GSR 494mm)

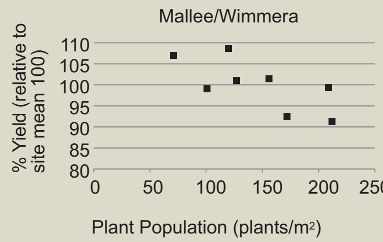
Murtoa rainfall 2003 = (GSR 381mm)

Inverleigh rainfall 2004=(GSR 361mm)

Birchip rainfall 2004 = (GSR 176mm)

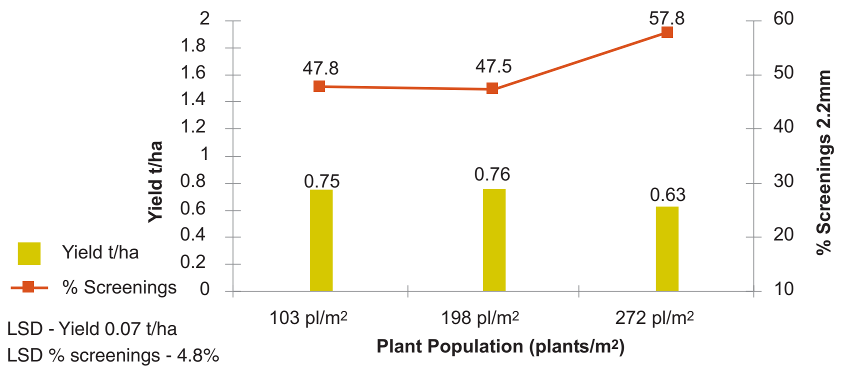
Influence of plant population on wheat yield – Project Trials 2003 & 2004





Link between canopy density and screenings - Gnarwarre 2003 HRZ – Barley

Link between canopy density and screenings Birchip 2004 Mallee - Barley



Consequences of excessively thick crop canopies

Whilst excessive plant populations may not produce yield differences there could be large effects on quality due to grain size. Very high plant populations (200 plants/m^2 plus) producing higher ear populations create smaller grains, which reduces quality. This is specially important in barley where screenings in particular are clearly linked to excessive canopy density.

Sowing rate calculations

To calculate sowing rates you will need to know the following:

- The plant population you wish to establish (plants/m^2)
- The thousand seed weight (TSW) of the seed
- The % germination of the seed
- The expected crop emergence – determined by seedbed conditions and seed quality

$$\text{Sowing Rate (kg/ha)} = \frac{\text{Target Plant Population (plants/m}^2\text{) x TSW (g) x 100}}{\text{\% germination x \% emergence}}$$

Key Points (for May/early June sowings)

- Plant cereal crops by seed number with a known target plant population in mind. Planting by the same calibration weight each year :
  - Takes no account of seasonal variation in grain size
  - Potentially wastes money on seed not needed
  - Creates the wrong crop structure for yield and quality
  - Loses control of canopy structure from the start!
- In the high rainfall zone there was a tendency for plant populations around and below 100 plants/m^2 to be lower yielding such that economically the optimum population was approximately 150 –200 plants/m^2.
- Under drier conditions in the Mallee and Wimmera optimum plant populations were lower at 100 –150 plants/m^2.
- Within each target population range consider lower end of range for earlier planting (assuming earlier germination) with upper end of range for later sowings.
- Thick crop canopies created by excessive plant populations (over 200 plants/m^2 whilst not always yielding less produce excessive tillers/heads which reduce the quality of the grain, particularly with barley.
- Where increased tillers/m^2 have been associated with yield increases, it has been the result of compensating for below optimum plant populations.

Canopy management – Influence of nitrogen timing and rate

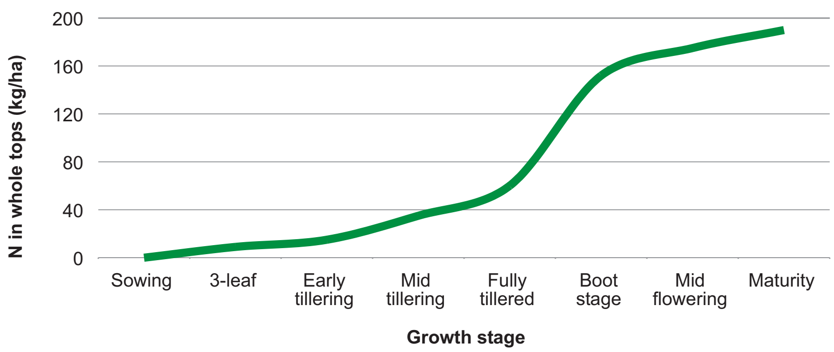
Will the nitrogen management timings that are inherent in European and New Zealand management strategies work under dryland and high rainfall zone (HRZ) conditions in Australia?

Though there is a plethora of previous data on nitrogen application in Australia, little of it has been targeted specifically on the growth stages used in European production systems. The principal focus of canopy management work has been to question whether Australian cereal crops receive too great a proportion of nitrogen too early.

Uptake of nitrogen in wheat by growth stage

Nitrogen timings for autumn sown cereals in high rainfall zones of Europe and New Zealand are based on nitrogen applications at early stem elongation, this is based on the understanding that this period marks a considerable increase in plant demand for nitrogen.

Relationship between cereal growth stage and nitrogen uptake kg/ha N (in whole above ground biomass) – Source 2004 GRDC Adviser Update (acknowledgement C.Walker, Incitec Pivot Ltd)



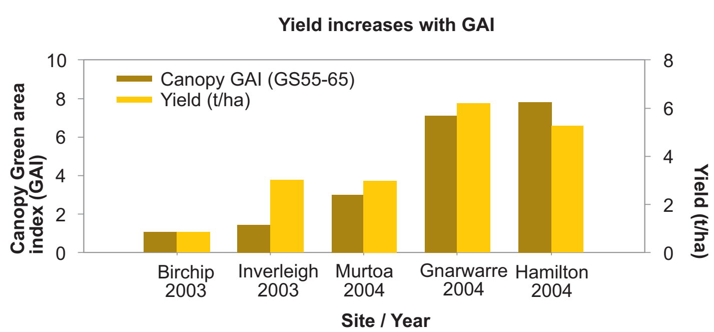
Influence of nitrogen timing on canopy size in wheat

In comparing different project trial sites, it is apparent that larger crop canopies have greater yield potential.

What characterises the differences between these crop canopies other than growing season rainfall and climate? Crops with larger canopies are characterised by:

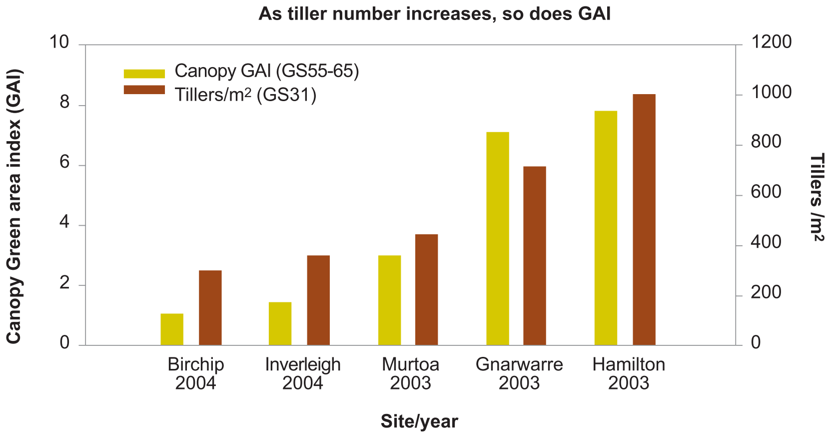
- Increased shoot (tillers) number
- Increased ear (head) number
- Larger leaves and longer stems

One way in which the grower can adjust canopy size is by manipulating tiller number and subsequent ear numbers with nitrogen timing.



Canopy Management

Higher tiller numbers = Larger canopies

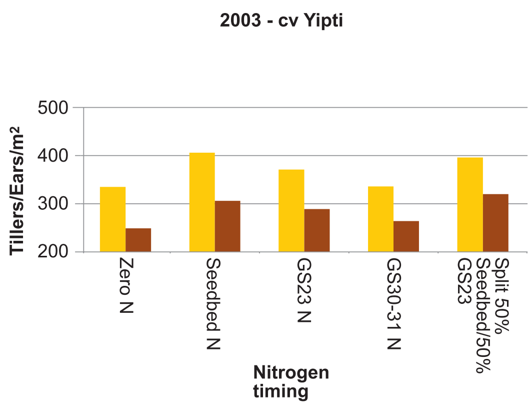


From this comparison it is clear that tiller number/m² is a key determinant of canopy size and thus potentially for yield.

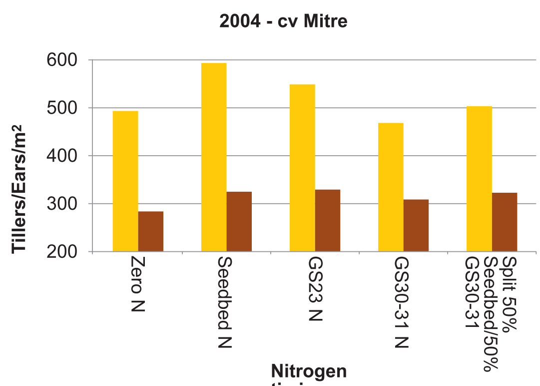
Larger Crop Canopies	⟷	Small Crop Canopies
have more tillers/m²		have less tillers/m²

Earlier nitrogen timing creates higher tiller number and thus larger crop canopies

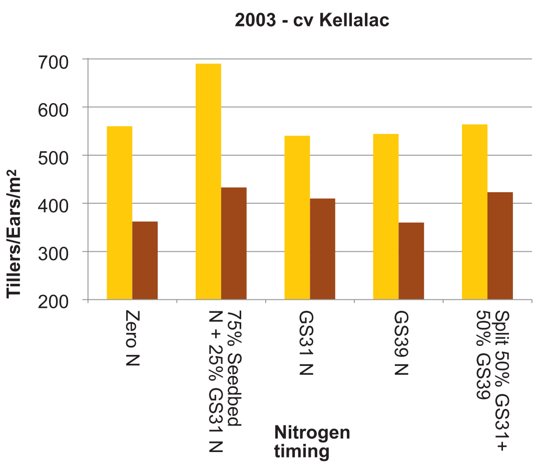
Murtoa 2003 - Wimmera

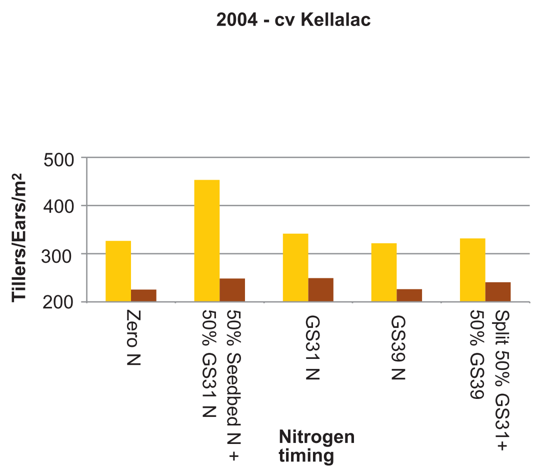


Lubeck 2004 - Wimmera



Geelong (Southern Victoria)





Note that the increased tiller number associated with earlier nitrogen translated into greater ear number in 2003

Earlier timed nitrogen increases tiller numbers and in many cases final ear number – but does it equal more yield?

No!

From a comparison of canopy sizes at different locations it might seem logical to conclude that for any individual site in any one season larger canopies will have higher yield potential. However this is incorrect. In project trials larger canopies created from earlier nitrogen timing have not increased yield.

In the project it was found that moving the majority of nitrogen away from planting to early stem elongation reduced tiller number and canopy size but did not reduce yield.

Influence of Nitrogen timing on wheat yield - 2003 (trial results GRDC project SFS 00006)

	Nitrogen regime/timing					
Variety	Untreated with N		Seedbed N*		GS30-31 N	
Trial location	Yield t/ha	%	Yield t/ha	%	Yield t/ha	%
Geelong, VIC Kellalac*	4.98	100	5.98	120	6.22	125
Geelong, VIC Mackellar*	5.42	100	6.09	112	6.26	115
Hamilton, VIC Kellalac*	4.68	100	5.25	112	5.12	109
Hamilton, VIC Mackellar*	5.69	100	6.38	112	6.22	109
Wimmera, VIC Yipti	2.44	100	2.98	122	3.12	128
Mallee,VIC Yipti**	2.66	100	2.85	107	3.05	115
Mean	4.31	100	4.92	114	5.00	116

*At least 75% of nitrogen applied in the seedbed

** Statistical difference in yield due to N timing

Influence of Nitrogen timing on wheat yield - 2004 (trial results GRDC project SFS 00006)

	Nitrogen regime/timing					
Variety	Untreated with N		Seedbed N/GS31*		GS30-31/GS39*	
Trial location	Yield t/ha	%	Yield t/ha	%	Yield t/ha	%
Geelong, VIC Kellalac	2.71	100	3.01	111	2.96	109
Geelong, VIC Mackellar	3.10	100	3.59	116	3.27	105
Conmurra, SA Mackellar**	4.08	100	4.67	114	5.04	124
Wimmera, VIC Yipti	1.89	100	1.81	96	1.85	98
Mallee,VIC Yipti	0.94	100	0.66	70	0.70	74
Mean	2.54	100	2.75	108	2.76	109

*50/50 split nitrogen applications compared at Geelong and Conmurra i.e. early split v late split.

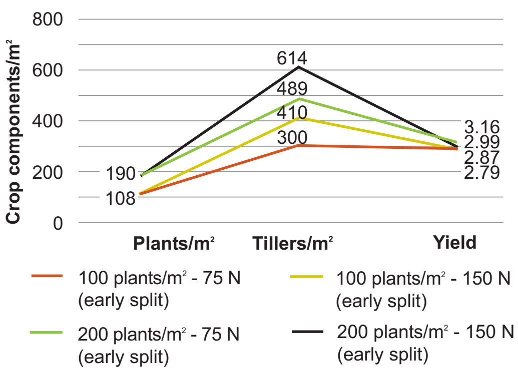
** Statistical difference in yield due to N timing

At individual sites despite large variations in tiller numbers due to nitrogen timing the effects on yield were small.

These results and specific site observations make it difficult to suggest (target) specific tiller populations at GS31.

Influence of plant population, nitrogen rate and timing on crop structure and yield of Kellalac wheat - SFS

Inverleigh, Victoria 2004



Early split = 50% N seedbed/50% GS30-31

LSD-Kellelac 0.17 t/ha, 84 tillers/m²

Zero N Plots

Kellalac 2.71 t/ha

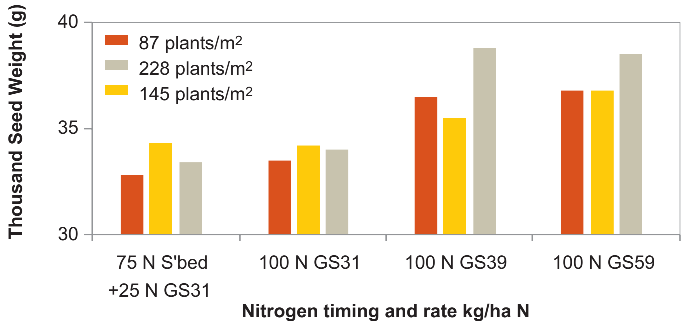
Why do we need to consider canopy management if different sized canopies yield the same?

If the canopy size, as defined by the ear number and tiller number, was much smaller when nitrogen was delayed from the seedbed, why was the yield unaffected on the majority of occasions?

The answer appears to be that the crop compensates by increasing the other two components of yield – grain size (thousand seed weight) and number of grains per ear.

Though not so apparent in the 2004 season, part of the reason for this compensation could be seen in crop canopy duration, later nitrogen application keeping the crop greener for longer.

Later nitrogen resulted in crop canopies that produced larger grains - Gnarwarre, Geelong - 2003



Zero N plots

Kellelac

87 plants/m^2=36.7g

145 plants/m^2=37.6g

228 plants/m^2=37.5g

Later nitrogen resulted in crop canopies that stayed greener longer in 2003 but not in 2004

Birchip cv Yipti (Mallee) 2003

Seedbed nitrogen (35kg/ha N)

GS31 nitrogen (35 kg/ha N)

Gnarwarre cv Mackellar (HRZ) 2003

Seedbed N

GS39 nitrogen

Key Points

- Creating larger canopies with earlier timing of nitrogen to boost canopy size did not create higher yields in either the high rainfall trials or the Mallee/Wimmera trials.
- Cereal canopies created from early stem elongation (GS30 – 31) nitrogen application produced crop canopies with fewer tillers and ears but were not lower yielding than larger canopies created by more upfront nitrogen.
- Smaller crop canopies compensated with larger grain size and more grains per ear. In some situations this compensation was associated with the crop canopy staying greener for longer.

Advantages of nitrogen applied at early stem elongation GS30-31

If the project work has rarely shown any yield benefit from early stem elongation timings in the two years of trials what, if any, is the advantage over upfront nitrogen application?

The principal benefits of applying a greater proportion of nitrogen at early stem elongation are fourfold:

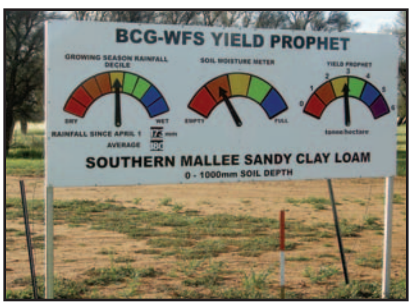
1. Better N use efficiency and quality of grain

Provided fertiliser is taken up, crops that are top-dressed at early stem elongation display greater nitrogen efficiency producing similar yields but higher proteins. Lower tiller numbers and, in some cases lower ears/m^2 produce larger grains which reduced screenings and increased test weight, particularly in barley.

2. Better match of nitrogen with crop need and soil water availability

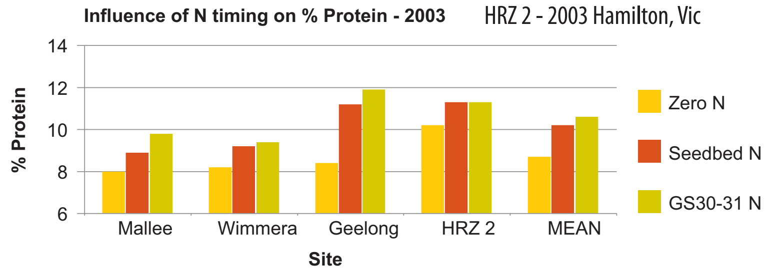
Crops top-dressed at early stem elongation are better matched to soil moisture levels. Decisions on the need for nitrogen fertiliser can be made with better knowledge of the crop's yield potential in late August (GS30) than in May and June.

Seedbed Nitrogen application ⟷	**GS30-31 Nitrogen application**
Low crop demand	High crop demand
Water limiting season	Water limiting season
Consequences	
Thicker vegetative canopy (haying off)	Thinner canopy reduced dry matter
Excess tillers, poor grain	Poor uptake, no protein advantage
Low yield	Low yield

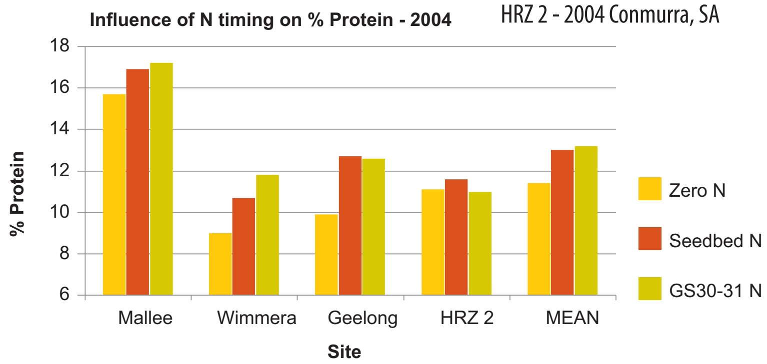


Moving nitrogen application later increases grain protein

HRZ 2 - 2003 Hamilton, Vic



HRZ 2 - 2004 Conmurra, SA

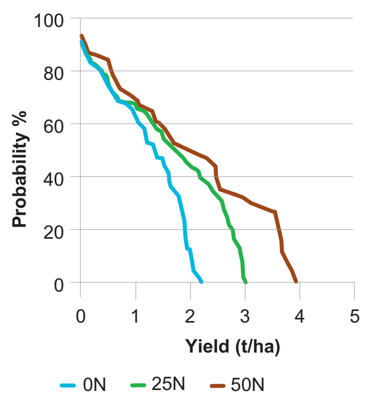


3. Better use of predictive models and SOI

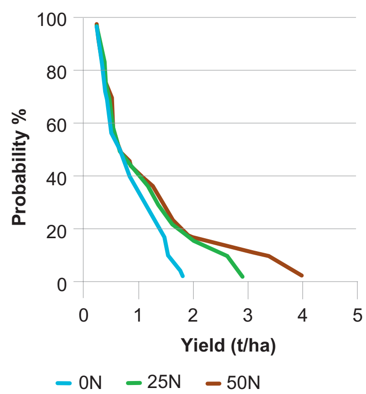
The ability of predictive models such as APSIM to use 2-3 months of the growing season's weather data before assessing yield potential at stem elongation (August) offers an advantage over sowing forecasts based on May and June sowings.

In addition, recent work on the Southern Oscillation Index (SOI) has suggested that the correlation between winter SOI and subsequent spring rainfall is much stronger than the correlation between autumn SOI and spring rainfall, giving growers greater opportunity to assess whether nitrogen is needed.

Birchip, Victoria (Mallee) May 1 2004 - Pre-sowing APSIM simulations for three rates of N (May 1, 2004)



Birchip, Victoria (Mallee) August 1 2004 - Modelled output on the 1 August, 2004 for a 'negative' phase of the SOI for June and July.



4. **Use of higher nitrogen rates and risk of leaching**

In those seasons where soil moisture levels give greater confidence of a nitrogen response, higher nitrogen rates can be employed in the spring without creating overly thick crop canopies that are prone to lodging. In addition risk of leaching would be much greater with increased pre winter doses since the root system of the plants is not fully developed.

Disadvantages of nitrogen applied at early stem elongation GS30-31

The principal risks associated with GS30-31 N are:

1) **Uncertainty of rain to provide uptake**

This is the key concern with most growers, however the window of application during early stem elongation is not critical, particularly if soil nitrogen reserves are relatively high.

2) **Crop wheelings in the absence of tramlines**

This is an issue with flag leaf (GS39) applications for protein enhancement but should be less of an issue at early stem elongation (GS30-32) due to crop compensation.

3) **More weed competition**

Rather than using nitrogen it would be better to use plant population to manipulate crops for weed competition. Barley is more competitive than wheat.

4) **Area to be top dressed**

There could be a constraint in applying nitrogen to large areas in the GS30-32 window of time.

What about barley?

Since stem elongation nitrogen is associated with higher proteins, malting barley growers need to be aware that whilst delayed nitrogen timing can be just as useful in barley, higher proteins may need to be countered with lower total nitrogen doses if a greater proportion of nitrogen application is moved from seedbed to stem elongation. Initial work with canopy management in barley produced very encouraging results in the HRZ trial at Inverleigh last season.

Key Points

- Take account of nitrogen in the soil prior to applying the main dose of nitrogen; remember cereal crops have a small requirement for nitrogen up to stem elongation (GS30). In most cases soil nitrogen and small doses of nitrogen (10-20 kg/ha N) applied with basal fertiliser should be sufficient for crop needs up to stem elongation.

High rainfall zone cereal production

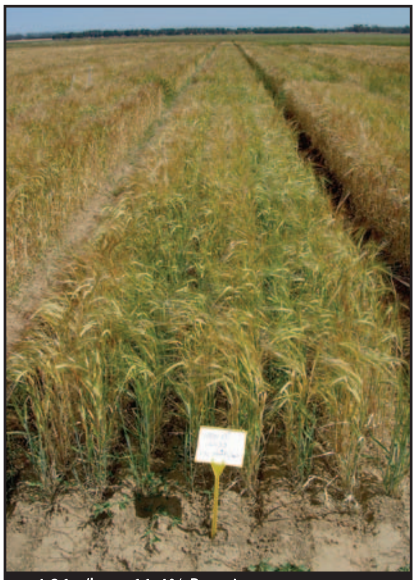
- If currently placing large amounts of nitrogen in the seedbed consider experimenting with a larger proportion of the N dose applied at GS30-32.
- Where nitrogen application is already centred on GS30-32 and proteins are too low consider split applications that concentrate the higher percentage of the N dose at the GS30-32 phase with a smaller proportion later at GS39 (flag leaf emergence).
- It is better to regard the N at GS39 as a protein dose rather than a yield dose. If too much N is removed from the start of stem elongation the crop will be unable to compensate fully for the loss of tillers in the event of poor uptake due to dry conditions.

Mallee/Wimmera

- In these regions crops may not always benefit from nitrogen, particularly in dry seasons, so consider delaying main expenditure on nitrogen until early stem elongation with initial crop needs serviced by nitrogen in the soil and small nitrogen doses applied with basal fertiliser.

Comparison of early (on left) and late (on right) nitrogen with yield and quality (Inverleigh, Victoria 2004)

3.34 t/ha · 11.8% Protein
4.0% Screenings · 63 kg/hl

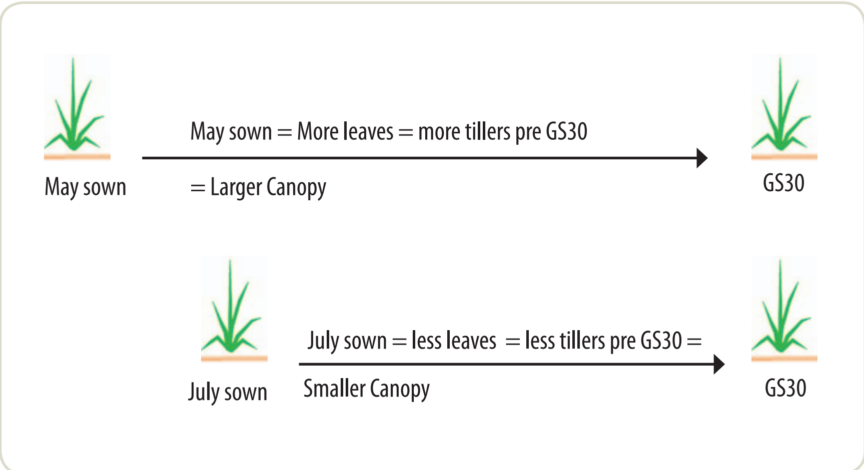


4.31 t/ha · 11.4% Protein
1.8% Screenings · 65 kg/hl

Canopy Management

Canopy management
– Influence of sowing date

The date of sowing influences the rate of crop development. Earlier sowings pass through the different development stages slower whereas later sowings develop more quickly. The number of leaves that the plant produces in the course of the season is also affected by sowing date (earlier sowings invariably produce more leaves between sowing and flag leaf). Since each leaf possesses a tiller bud, the number of tillers increases with earlier sowings:



Early sowings develop more slowly giving more time for tillering prior to stem elongation at GS30.

Later sowings develop faster giving less time for tillering.

Key Points

- To take account of sowing date remember earlier sowings → more leaves = more tillers per plant → greater proportion likely to survive since longer period for growth (emergence to GS30).
- When planting earlier (assuming earlier germination) it is important to reduce plant population to take account of higher tiller numbers and stronger nature of tillers (unless the effect has been created for grazing purposes).

3. Disease Management in Cereals

Why fungicides?

Fungicides do not create yield they only protect an inherent yield potential that the crop would have delivered free of disease. Economic response is related to the extra green leaf retention associated with fungicide use, particularly during grain fill. For a given level of disease, restriction in soil moisture, particularly during grain fill, reduces the difference in green leaf retention between fungicide treated and untreated crops and therefore the yield response.

How do fungicides work?

All fungicides work more effectively when applied before disease becomes established in the leaves. Foliar applied fungicides do not properly protect leaves which are un-emerged at the time of application as they have limited systemic movement in the plant.

Fungicide timing

For single spray options, flag leaf emergence on the main stem is the key leaf to protect in wheat (GS39). In barley, the second last leaf formed is the key leaf. This is the leaf below the flag and is termed flag minus 1 (F-1). This leaf appears at approximately the third node stage (GS33).

Management Strategies

Foliar fungicides are insurance policies since their principal benefit is realised after application. Australian conditions and results from this project illustrate that the cost of this insurance policy should be kept at a minimum in order to make money from fungicides.

Strobilurin fungicide response

Results show that strobilurins offer a greater degree of protection than other available fungicides, however wheat diseases such as stripe rust can be controlled very effectively by triazole fungicide spray programmes costing little more than $10/ha (not including cost of application). Thus for the vast majority of situations, based on current costs, it is difficult to justify the use of the new strobilurin fungicides, unless faced with severe disease pressure in a very high yielding situation.

1. Why Fungicides?

Why do we apply fungicides – what are we trying to achieve?

Fungicides are used to make money, therefore though disease may be present in a crop at many stages through the crop's life it may not always be economic to control it. Therefore as an input, the economic response to fungicide relates to the:

- Extent of the disease pressure
- The ability of the product to control that disease
- Water availability to the crop to express the benefit

It is important to understand which plant structures (leaves, stem and ear) contribute most to yield and to determine when growing conditions (soil water) will allow any benefit to be expressed. Economic response from fungicides has two distinct but strongly related components, yield and quality.

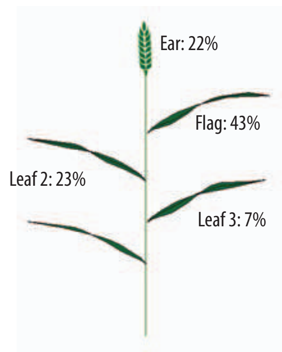
What are we trying to protect?

Disease control on the yield contributing leaves
↓
Disease free canopy during grain fill → Improved grain fill
↓
larger grain size
↓
improved yield
↓
improved quality characteristic.

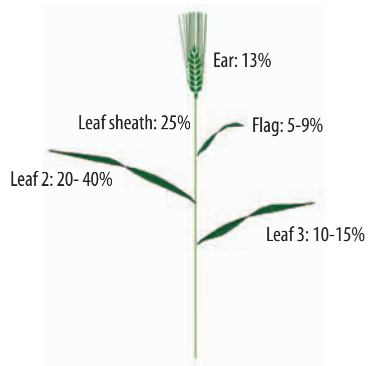
Whilst the number of fungicide applications, rate and specific timings will relate to disease pressure and yield potential, it is important to recognize that fungicide application should also be related to the importance of the plant components being protected.

Approximate yield contribution of top three leaves in cereals (based on UK/NZ data)

1. Winter wheat



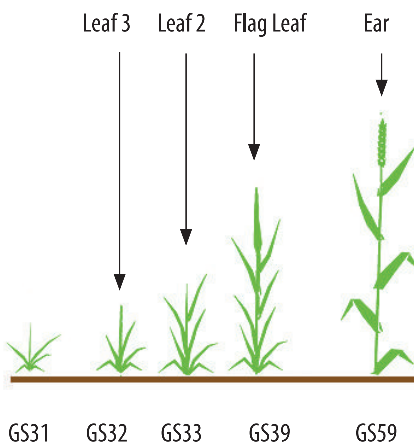
2. Winter barley



- Note that since the size of the final 3 leaves in wheat and barley differs, so does their contribution to grain yield. As a result fungicide strategies have slightly different emphases depending on the importance of the leaves being protected.
- These examples do not infer that the roots are not important but rather that the flag leaf provides approximately 45% of the yield in wheat, whether it be a 2t/ha crop because of rooting problems or a 7t/ha crop with good root system and water availability.

When do these important leaves emerge?

If the objective of a fungicide strategy is to protect the most important leaves, then it becomes important to identify when the top 3 leaves emerge. In terms of the Zadoks growth stage key the top 3 leaves and ear emergence are covered by GS32-59 i.e. the start of stem elongation to full ear emergence. Thus for example at GS32 the leaf emerging from the main stem is likely to be leaf 3 or (F-2).



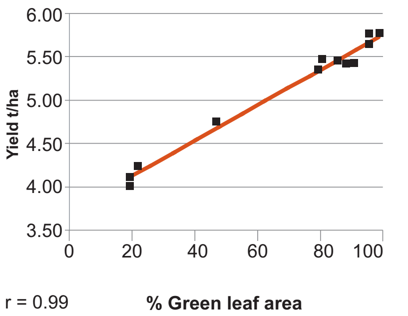
Leaf tagging is a useful method of tracking which leaves were sprayed with fungicide in early stem elongation.

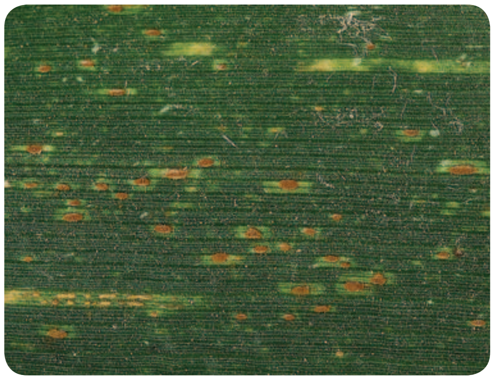
Keeping the canopy disease free during grain fill

Where disease is destroying canopy during grain fill there are good correlations between green leaf retention due to fungicide application and final yield.

Correlation between green leaf area @ GS72 and yield in the presence of stripe rust

H45 southern NSW (fungicide treatments only)





Leaf rust particles (brown larger pustules)

Stripe rust (yellow smaller pustules)

Fungicide as an insurance

Fungicides should be applied before the top three leaves become infected and yet have their greatest impact during grain fill. Fungicide application is always likely to be an insurance-based input.

Constraint of water availability

As an insurance input it is difficult to take account of subsequent weather conditions during grain fill (other than from predictive models based on historical weather data). Unfortunately in Australia high temperatures and reduced water availability during grain fill have a far greater ability to reduce green leaf retention than disease.

This can be clearly seen from 2004 project data comparing susceptible wheat in the Wimmera with similar sowings in southern NSW. Both situations suffered stripe rust, which destroyed similar green leaf area during grain fill (approximately 40% of F-1 at the end of October). In the Wimmera scenario the green leaf retention of the treated crop was reduced in both area and duration by lack of soil moisture.

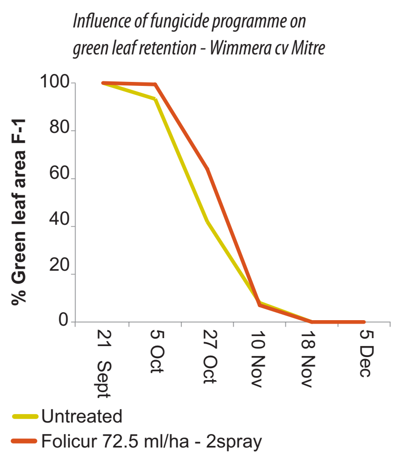
The small yield response in the Wimmera was not due to lack of disease control in the treated crops but lack of green leaf retention in the treated crop due to soil moisture availability and a truncated grain fill period.

As part of the project, work in New Zealand studied the influence of different water availability in grain fill for a given stripe rust disease infection.

Influence of water in early grain fill with and without fungicide application in the presence of a stripe rust infection (Opus 0.25 l/ha + Amistar 0.25) – cv Amarok, Canterbury Plain, NZ.

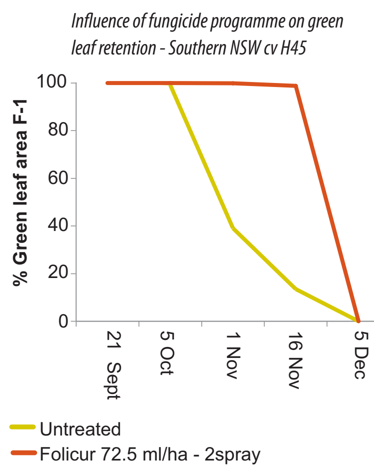
Wimmera, Vic – Oct rainfall 7.5mm

Response to fungicide – 0.3 t/ha

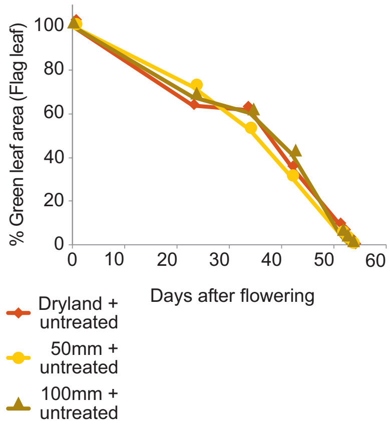


Young, NSW – Oct rainfall 28mm

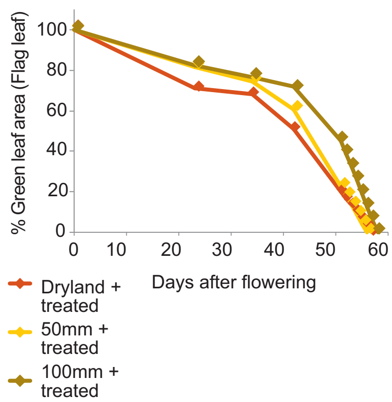
Response to fungicide – 2.01 t/ha



Influence of increasing water in an untreated crop

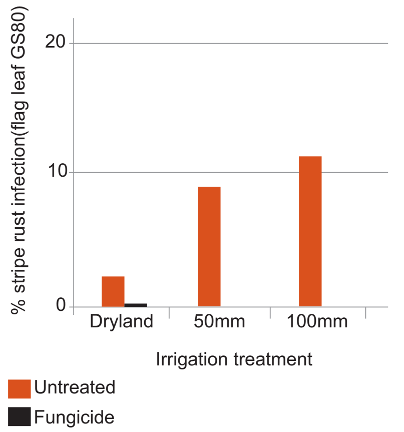


Fungicide effect on green leaf retention as water increases



- As the water available for grain fill increased so did the impact of fungicide on green leaf retention in the presence of stripe rust.
- Where crops were untreated with fungicide, increasing water did not create the advantage in % green leaf retention, since the level of stripe rust.

Stripe rust infection increased with greater water availability during grain fill



Knowledge of soil water availability at flag leaf (GS39) and rainfall probabilities for grain fill will dictate:

- The need to apply a fungicide
- Level of expenditure for the fungicide

For disease management prior to flag leaf emergence (GS39), soil moisture is less of a consideration due to threat of an earlier epidemic being more damaging to yield.

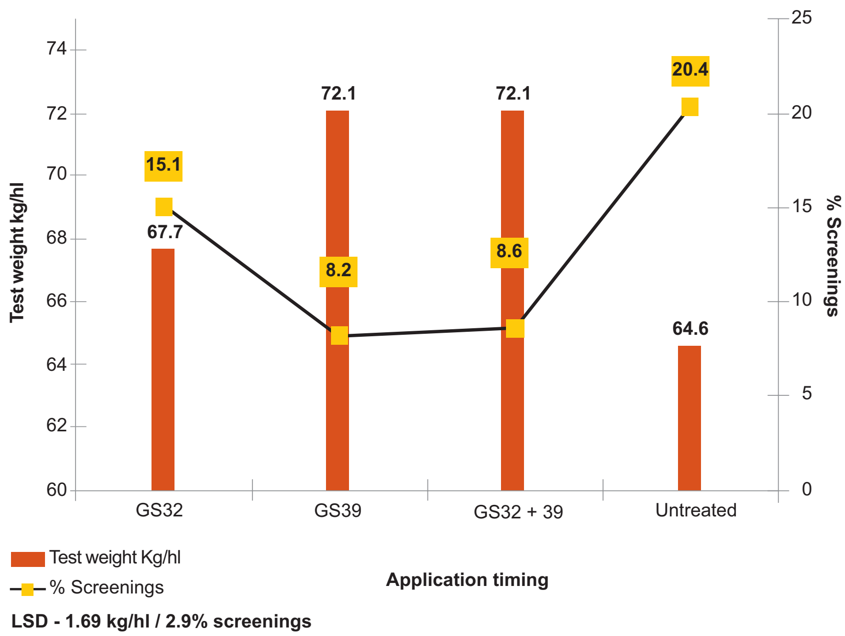
Key Points – Yield responses from fungicides

- Yield response from fungicides is linked to the differences achieved in green leaf retention, principally during grain fill.
- In order to achieve differences in green leaf retention during grain fill it is important to target the leaves that contribute most to yield: Flag leaf in wheat and leaf 2 (leaf below flag) in barley.
- Fungicides are insurance inputs: applied during stem elongation yet having their greatest impact during grain fill.
- In the presence of disease, link fungicide application and cost to historical/ predicted rainfall during grain fill and current soil water availability.
- For a given stripe rust scenario, increased water availability is likely to increase disease pressure and generate greater green leaf retention and thus yield from fungicide application.

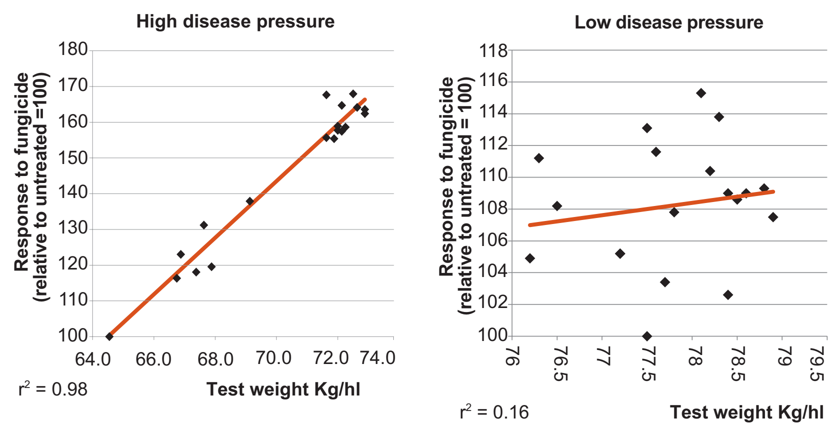
Influence of fungicide on quality

It is important to recognise that where there are yield increases due to fungicide application there are invariably grain quality effects. The majority of these effects are positive for most market outlets.

Influence of stripe rust control with fungicides on test weight (kg/hl) and % screenings – Harden, NSW 2003



Correlation between test weight and % yield response to fungicide



Disease Management

Key Points – Quality responses from fungicides

Grain size - much of the yield increase with a fungicide is achieved by increasing thousand seed weight. Therefore grain size is heavier and larger.

% Screenings - as a result of larger grains there are fewer screenings where fungicide generates yield responses.

% Grain protein - as a result of better grain fill grain protein content can be reduced.

Test weight kg/hl - where fungicides have a large influence on yield, test weights are strongly correlated.

Sample appearance - with particularly wet harvest periods later fungicide application can improve sample appearance purely through the control of late occurring saprophytic diseases such as sooty moulds.

Overall, the economics of fungicide application has to be assessed in terms of both yield and quality effects. However it is unusual to secure large quality benefits unless the fungicide has created a yield effect in the first place.

2. How do fungicides work?

All fungicides work more effectively when applied before disease becomes established in the leaves to be protected.

In order to time foliar fungicides correctly we need to appreciate how these agrichemicals work in terms of movement and control of the pathogen. As a broad generalisation foliar fungicide activity can be described in one of two ways:

Protectant activity – is activity usually associated with the surface of the plant that confers protection against future spore infection, the length of the protection is termed the degree of persistence. Fungicides that are purely protectant, such as chlorothalonil, have no ability to control disease already present within the leaf i.e. it is not systemic.

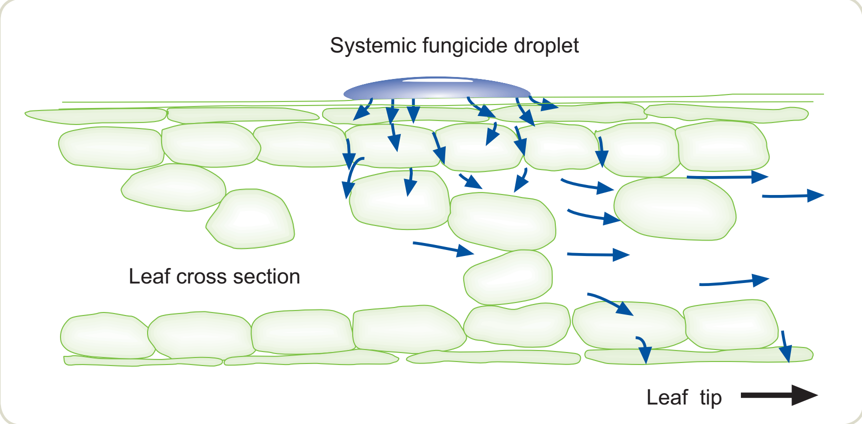
Or

Curative activity - is the ability of a fungicide to destroy disease after infection has occurred (infection developing within the plant), it requires the fungicide to enter the plant tissue i.e. it exhibits a degree of systemic activity. Foliar fungicides currently approved for use in Australian cereal crops all fall into this category.

How do fungicides move?

When applied to the leaf tissue all of the fungicides currently approved for cereals move in the same way.

- Cereal fungicides move towards the leaf tip. The fungicide diffuses into leaf surface and then travels via the water carrying vessels (xylem) towards the leaf tip (they are unable to travel downwards when inside the leaf).
- Different fungicide actives move at different rates and determine how fast the products work and how quickly the product's activity dissipates. The newer strobilurin fungicides such as Amistar Xtra, containing azoxystrobin, move very slowly compared to triazoles such as flutriafol (Impact) and cyproconazole (triazole in Amistar Xtra).



The movement of fungicide active ingredients can be seen with the use of radioactive droplets applied at the base of the leaf. This illustration shows the degree of movement 3 days after application of individual droplets at the base of the leaf.

Red colouration denotes greatest concentration of labelled active ingredient and blue denotes no active present.

Curative activity – a false sense of security!

The ability of these products to provide curative activity can give growers and advisers a false sense of security with regard to controlling disease in the crop. The ability of these products to control disease after the date of infection (so called "kickback activity") is limited to approximately 10 days maximum depending on temperature, rate and product. Where disease infection has been present in leaf tissue for longer than this, the fungicide will not be able to prevent visible leaf damage.

Fungicides work more effectively before disease becomes established in the leaf to be protected.

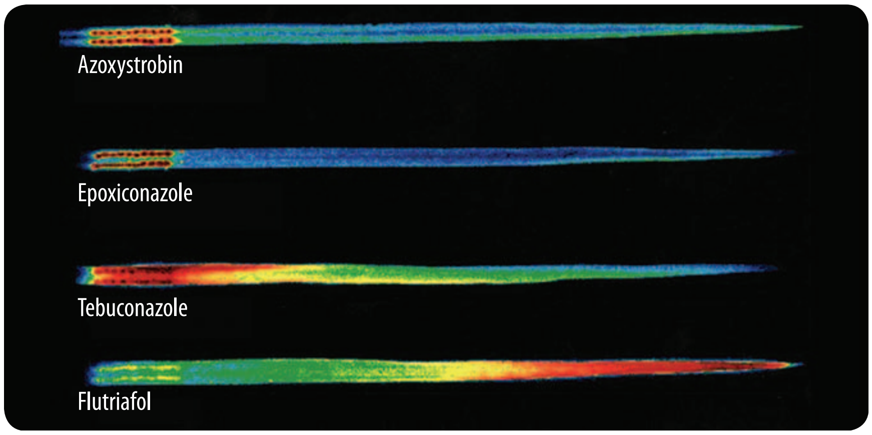
Currently available foliar fungicides used in Australian cereal crops

With reference to cereals most of the commonly used fungicides in Australia for foliar disease control are to be found in the same chemical family, **Group C DMI's** (Demethylation inhibitors). This group is often referred to as the triazole or azole group.

The **Strobilurins, Group K**, is a new group of fungicides first introduced to the Australian cereal market in August 2004 (Amistar Xtra).

Systemicity in wheat

3 days after application



(Courtesy of D W Bartlett, Syngenta – Jeallot's Hill International Research Centre)

Group C – DMI's Azole Fungicides

Chemical Name	Trade Name	Registered in Australia for use on	
		Cereals	Other Crops
Difenoconazole	Score	No	Yes
Epoxiconazole	Opus	Yes	No
Cyproconazole	Alto	Yes*	Yes
Flusilazole	Nustar	No	Yes
Flutriafol	Impact	Yes	Yes
Fluquinconazole	Jockey (seed trt)	Yes	Yes
Propiconazole	Tilt/Bumper	Yes	Yes
Tebuconazole	Folicur	Yes	Yes
Triadimefon	Triad/Bayleton	Yes	Yes
Triadimenol	Baytan (seed trt)	Yes	No

* Available in cereals only in mixture with azoxystrobin (Amistar Xtra) and with propiconazole (Tilt Xtra)

Group K – Strobilurin Fungicides

Chemical Name	Trade Name	Registered in Australia for use on	
		Cereals	Other Crops
Azoxystrobin	Amistar	Yes*	Yes
Pyraclostrobin	Cabrio	No	Yes
Trifloxystrobin	Flint	No	Yes

* Available in cereals only in mixture with cyproconazole (Amistar Xtra)

How does the fungicide kill the fungus?

Different fungicide groups have different modes of action to kill the fungus.

Group C DMI

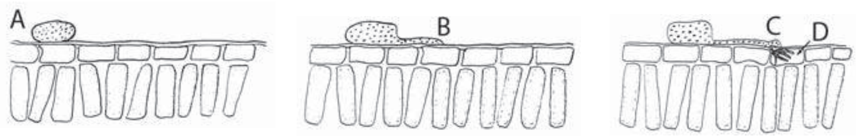
Azoles or triazoles work by disrupting the manufacture (biosynthesis) of a fungal cell membrane component called ergosterol.

Group K Strobilurin

The strobilurins act on the fungal cell components called the Mitochondria, which are the cell organelles responsible for producing the chemical energy that drives the development of the fungus. The cellular process interrupted is called **Respiration.**

This difference affects the point at which germinating fungal spores are controlled.

Fungal spore germination and development



1. Spore infection

A- Spore lands on leaf

Activity: Strobilurins Yes

Triazoles No

2. Spore germination

B- Germination tube

Activity: Strobilurins Yes

Triazoles ½

3. Fungal penetration

C- Appressorium

D - Infected cell

Activity:

Strobilurins No/limited

Triazoles Yes

Strobilurins are able to destroy the spore before it germinates, since germination is an extremely energy demanding process whereas triazoles only start to work when the germinating spore requires ergosterol (initial spore germination is carried out using reserves of this compound). Strobilurins work most effectively on the surface of the leaf and make extremely good protectants but are relatively poor curative materials.

In contrast triazoles are better curative materials working well inside the leaf, however entry into the leaf also marks the gradual dissipation of the material as the active moves to the leaf tip, eventually leading to inadequate concentrations for protection.

Influence of strobilurin/triazole mix on Scald in the Tasmanian HRZ (treated on right, untreated on left)

Key Points

- Cereal foliar fungicides do not move down the plant, movement in the leaves and stem is upwards towards the leaf tip via the water carrying xylem vessels.
- Foliar fungicides applied to the leaves do not protect un-emerged leaves or the base of part emerged leaves, other than reducing inoculum levels on lower leaves.
- Movement in these xylem vessels is the same for triazole fungicides applied to the leaf or applied as a seed treatment. However the movement of active ingredient from the stem base into new tissue i.e. from in-furrow or treated seed is less constrained than applying fungicide to the leaf (since product cannot move back down the leaf).
- Fungicides are better employed before disease becomes established in the leaves to be protected. A delay in spraying increases the need for higher fungicide rates since there is more dependency on curative activity.
- Applying fungicide to a given leaf before infection becomes visible gives greater rate flexibility.
- Strobilurins are extremely effective protectants but poor curative fungicides.They have the ability to control disease and keep the crop greener for longer, provided there is sufficient soil moisture and plants are not subjected to excessive temperatures. (Note for cereals: strobilurins are only available in a mix with a curative triazole fungicide).
- Triazoles are, in contrast better curative products with variable protection characteristics depending on how long sufficient concentration can be maintained within the leaves (remembering that once inside the leaf the fungicide starts to move away from the point of contact with the plant).

3. Fungicide Timing

When should we employ foliar fungicides in cereals?

The optimum timing for foliar applied fungicides in cereals is from the start of stem elongation to ear emergence (GS 30 - 59). This period coincides with the emergence of the 4 most important leaves in the crop and the ear. The optimum time for spraying a fungicide to protect a leaf is at the point of full emergence. Leaves un-emerged at the time of application, will not be properly protected.

Leaves will usually be free from foliar disease on emergence!

The time between when the disease spores land on the leaf and when you can see visible infection point is called the latent period or latent phase. This period is temperature driven and differs between diseases, yellow leaf spot/mildew being very short - 7 days, whilst other diseases such as Septoria tritici may take 3 times as long. It means that shortly after emergence whilst a leaf may look healthy, disease can already be developing within the newly emerged tissue.

The first signs of disease in a new leaf is usually at the tip since this part of the leaf has been exposed to disease for longer.

If the crop is under disease pressure, the longer the spray is delayed after leaf emergence the more difficult it will be to control disease in that leaf, since the curative activity of most systemic fungicides employed is little more than 7-10 days. Therefore the trigger for spraying should not be the level of disease in the leaf you wish to protect but the leaf below it, combined with knowledge of weather conditions favouring the disease.

Key Points

- Depending on the leaf you wish to protect the aim should be to spray at, or near, full emergence of the target leaf.
- For single spray options flag leaf emergence on the main stem is the key leaf to protect in wheat (GS39).
- In barley leaf 2 is the key leaf - this is the leaf below the flag and is termed flag minus1 (F-1). This leaf appears at approximately the third node stage (GS33).

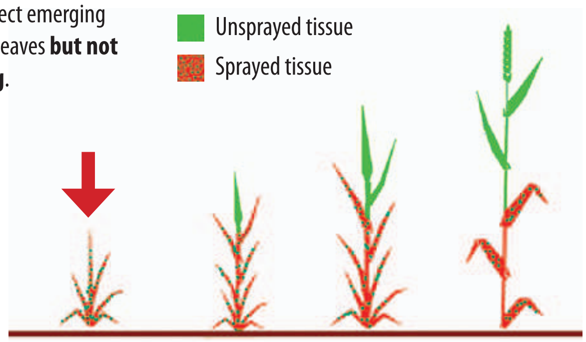
Foliar fungicide application in wheat at and prior to flag leaf emergence (GS30-39)

Flag leaf emergence GS37-39 (flag leaf visible – flag leaf fully emerged) is a pivotal growth stage for fungicide application, since fungicide applied at this stage means that all the top 3 leaves have been exposed to fungicide. Application before this growth stage means that there may be a need to consider a second application to protect leaves unemerged at application. Conversely, fungicide left until ear emergence (GS59) may result in significant damage as disease infects the top 2 most important leaves.

Thus spraying for disease:

- At second node (GS32) will protect emerging leaf 3 (flag minus 2) and lower leaves **but not leaf 2 (flag minus 1) and flag**.

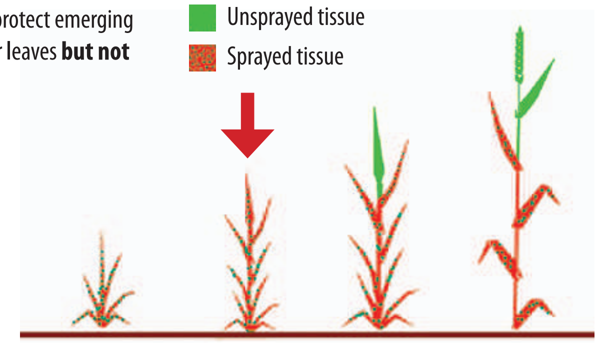
Which leaves are protected when you spray at GS32?



Growth stage	GS32	GS33	GS39	GS59
Emerging leaf	Leaf 3 (F-2)	Leaf 2 (F-1)	Flag Leaf	Ear

- At third node (GS33) you will protect emerging leaf 2 (flag minus 1) and lower leaves **but not the flag leaf**

Which leaves are protected when you spray at GS33?



Growth stage	GS32	GS33	GS39	GS59
Emerging leaf	Leaf 3 (F-2)	Leaf 2 (F-1)	Flag Leaf	Ear

- At flag leaf emergence GS39 all leaves will be directly protected provided canopy density does not prevent coverage or that infection has become established before GS39.

A single early fungicide applied before flag leaf emergence will not control disease in wheat. This has been demonstrated in a number of project trials.

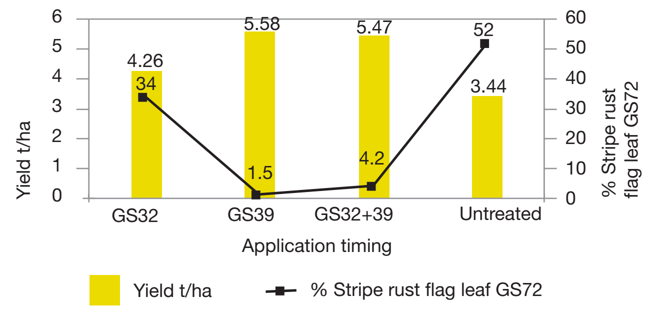
Where disease onset occurs early in stem elongation GS30 – 33 but before the flag leaf is visible it would be appropriate to consider a second fungicide timing at flag leaf or soon after if disease pressure is maintained.

So what timings should we adopt if infection occurs before flag leaf in wheat?

When disease infection moves into wheat before flag leaf emergence (GS37) a single fungicide may not be appropriate. A second spray needs to be considered. In barley, leaf 2 (F-1) is the most important leaf before GS33 therefore a follow up spray may be required. Project trials have addressed this issue by comparing the same amount of active ingredient split between pre and post flag leaf emergence either GS32/33 + 39/43 with a single application at GS39/45. In 2004 at Young, NSW two identical trials were sown a 1 month apart (June 6 and July 6). Stripe rust infection came into both trials in early October, however in trial 1 the crop was at flag leaf emergence whilst in trial 2 the crop had only reached second node.

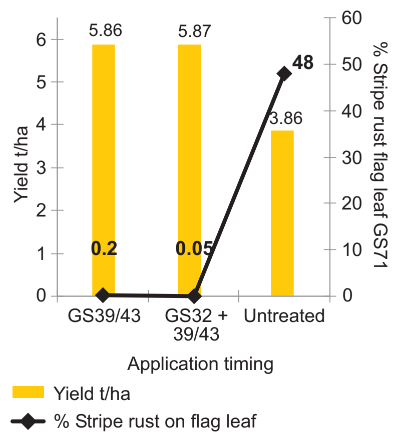
Stripe rust infection at GS59 in the South Australian HRZ

Influence of fungicide timing on stripe rust control and yield - cv H45, Harden, NSW 2003 (mean of 4 fungicide treatments using the same amount of active ingredient)



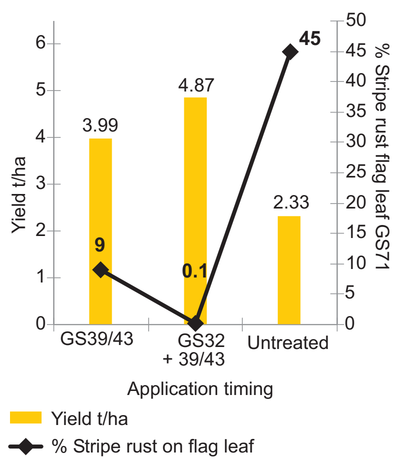
LSD -0.2 t/ha Disease assessed 42 days after GS39 application

Influence of fungicide timing on stripe rust control and yield - cv H45, young (trial 1), NSW - 2004 (using same amount of fungicide Folicur 145ml/ha)



Disease onset at flag leaf emergence GS37-39 - no value to splitting active

Influence of fungicide timing on stripe rust control and yield - cv H45, young (trial 2), NSW - 2004 (using same amount of fungicide Folicur 145ml/ha)



Disease onset at second node GS32 – large advantage to splitting fungicide into 2 sprays

Foliar fungicide application in cereals after flag leaf emergence (GS39 - 59) – Risk of a yield penalty

If the onset of disease occurs at or before flag leaf emergence GS39 and a single fungicide application is delayed beyond GS39, then the risk of yield penalty increases, particularly if the cultivar is susceptible to the disease. In the 2003 season there were a number of trials that indicated a yield penalty associated with delayed fungicide application after GS39.

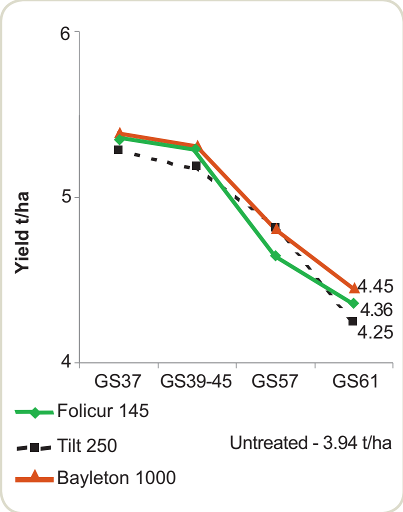
The yield results illustrated a worst case scenario loss of 1 t/ha between GS37 (flag leaf tipping) and GS61 (start of flowering), this equated to approximately 42kg/ha yield loss for every day of delay in applying the fungicide to this very susceptible variety.

Role of an ear emergence GS59 spray timing

Unless the crop is subject to very late disease infection, a single application at this timing will usually produce inferior results compared to applying at flag leaf stage. The traditional role of this spray timing is twofold:

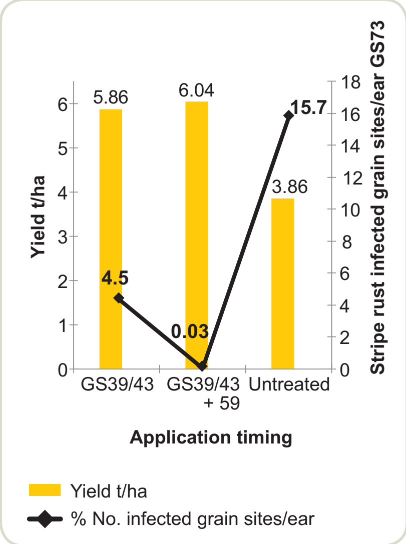
- it tops up the disease control in the top 2 leaves assuming an earlier flag leaf application
- protects the ear that was not emerged at the earlier spray timing e.g. stripe rust head infection

The relevance of this spray timing is increased in regions with longer grain fill periods when crops are under high disease pressure for the whole season. However, under Australian conditions responses are likely to be marginal, even with the most susceptible varieties, provided a flag leaf application has already been applied (the exception would probably be stem rust since it frequently expresses itself at or after ear emergence).

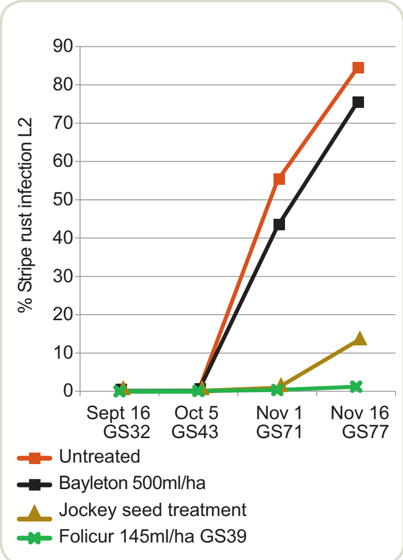


Influence of single fungicide timings and product choice on the yield of H45, Young, NSW

(Courtesy of Agritech and Chandlers Landmark 2003)



Role of an additional ear emergence timing following a flag leaf application control – cv H45, Wombat (Trial 1), NSW - 2004 (using Folicur 145ml/ha at both timings)



Comparison of seed treatment and foliar fungicide for control of Stripe rust - susceptible cultivar

Fungicide application before the start of stem elongation (GS30) – seed treatment v foliar fungicide

Assuming both options control the disease in question, applications of foliar fungicides before GS30 tend to be less effective than "upfront measures" such as broad-spectrum seed treatments and in-furrow treatments. At early growth stages such as tillering (GS 20-29), the growth of new leaves rapidly dilutes foliar fungicide activity. Since foliar fungicide sprayed onto young leaves cannot move backwards down the leaf into new leaves, fungicide active applied via the roots (in-furrow treatments) or from the base of the stem (seed treatments) has an advantage at these early growth stages. The upward movement of the active gives better protection of new leaves. This was illustrated in project trials run in NSW and South Australia in 2004 against stripe rust in wheat.

Later in the season at stem elongation the persistence of up front measures start to fade. In general, foliar fungicides are more suited to situations where the later-formed, more important, leaves are present.

Key Points

- Fungicides sprayed for disease before the important leaves emerge will require follow up sprays if disease pressure continues.
- Disease onset prior to GS37 requires the consideration of two fungicide applications.
- Broad spectrum seed treatments and in-furrow fungicide treatments feed active ingredient from the stem base. This gives more effective disease protection early in the season than foliar fungicides, particularly pre GS30. Unfortunately this superior activity fades as the more important leaves emerge.

4. Management strategy

How can we use this knowledge in a management strategy that integrates the likelihood of an economic response?

Foliar fungicides are insurance policies since the likelihood of response is related to subsequent grain fill conditions. More so than in other environments where fungicides are employed for cereal disease control Australian conditions dictate that the cost of the insurance policy should be kept at a minimum. The frequent occurrence of drier/hotter conditions during grain fill, reduce disease levels and green leaf retention created by the earlier application of fungicides. This is particularly apparent when examining the results of this project. In wheat growers are fortunate to have fungicide chemistry at their disposal, which provides excellent disease control at low cost (approximately $10/ha). There is no guarantee of an economic return growers can put in place relatively low cost insurance policies which work with the most susceptible varieties.

How can we determine disease risk?

So far we can deduce that:

i) Foliar fungicides are most effective when they are applied shortly after the emergence of the leaf you wish to protect (in practical terms this usually means long enough for the leaf to fully or nearly fully emerge on the main stems but before disease has expressed itself on that leaf).

ii) The top 3 leaves of the cereal canopy are the most important to protect along with the ear.

iii) The first of the important leaves emerge at the start of stem elongation.

This information tells us when to start considering whether a fungicide is worthwhile and which leaf is most important. What it does not tell us is the degree of disease pressure and its likely rate of disease development.

There are a number of factors to consider here but the starting point is likely to be:

i) Variety resistance – Timing by threshold or leaf emergence?

In more resistant varieties the disease epidemic is slower to establish and as a consequence will have less impact on yield potential. If the variety has a good resistance profile (MR – R rating) it is difficult to suggest a pre-programmed approach to protecting the top 3 leaves of the canopy. Instead it would be better to monitor the crop and respond to evidence of disease in the crop, even though this might mean that fungicides could be applied later than the optimum time.

Where varieties are more susceptible (MS or S rating), disease can build up more rapidly and earlier in the season. In these situations it would be better to base fungicide application on pre-programmed growth stages for fungicide application, but taking account of disease on lower leaves, weather conditions for disease development and reports of disease in the region at each critical growth stage.

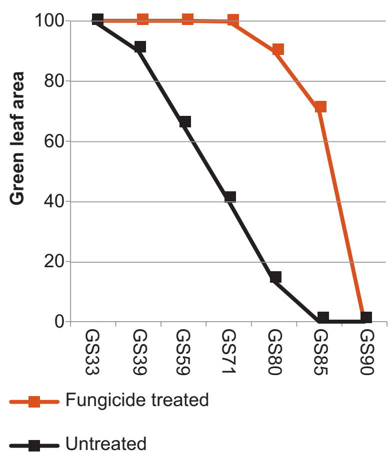
ii) Presence of the disease in the crop/ region and weather conditions for development

Though the length of the latent period potentially distorts this factor, most advisers/growers use their own crop as the threshold indicator for the need to spray a particular disease. Thus, with wheat, monitor disease levels from GS32 (2nd node) to GS65 (mid flower) and with barley from GS30-31 (start of elongation) to GS59 (ear emergence) using the presence of fresh infection on the lower leaves combined with the knowledge of the weather conditions that encourage that disease, on which to base a decision.

- Remember however, that a week of hot dry weather will not always stop disease immediately since latent disease will continue to express itself, the 2003 stripe rust outbreak being a case in point.
- In addition, with more susceptible crops, it is worth considering spraying on the basis of disease outbreaks in the region as well as your own crop.

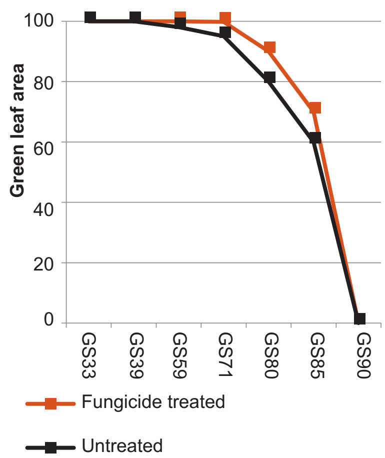
More susceptible varieties potentially lose greater green leaf area to disease and at an earlier growth stage therefore are more suited to fungicides timed by growth stage.

Susceptible variety



More resistant varieties prevent early build up of disease and do not lose the green leaf area to disease, as a consequence fungicide is better timed on a threshold basis.

Resistant variety



Management Strategies for Wheat

Consider variety resistance and the seed treatment utilised before monitoring. Remember both resistant varieties and broad-spectrum seed treatments will delay the build up of disease.

Irrespective of whether it is barley or wheat when fungicides are employed **timing is more important than product.**

Consider GS39 as the key timing for a single application to this crop.

For more stripe rust susceptible varieties – monitor at GS32 and GS33 and consider application if stripe rust is being reported as widespread (if Jockey seed treatment or Impact used in-furrow they may protect until GS39 or further in the case of Impact). Target main spray and expenditure at GS39. Do not omit the GS39 spray on the grounds that a seed treatment or an earlier spray was applied at GS32/33 since it won't protect the flag leaf, if the crop is under disease pressure. **There is no substitute for applying the fungicide to the leaf you wish to protect - post GS32.**

For the less important timings (e.g. sprays to protect leaf 3 or 2 applied at GS32 or 33) where a flag leaf (GS39) timing is pre-planned, consider cheaper products such as triadimefon (Triad/ Bayleton), particularly if the developing disease is rust or mildew.

For more stripe rust resistant varieties – consider a single application at GS39-59 only if disease builds up in the GS39-59 development period on leaves 2 & 3.

In terms of product choice consider products with longer persistence on rusts for the susceptible varieties at the GS39 timing for the high rainfall zone, particularly if there is a range of different diseases present – tebuconazole (Folicur), epoxiconazole (Opus) and cyproconazole/ propiconazole (Tilt Xtra). For shorter grain fill periods and stripe rust only scenarios consider triadimefon (e.g.) Bayleton.

Single application approach in wheat (flag leaf emergence)

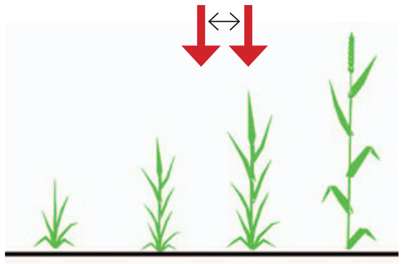
Timing – The optimum timing for a single spray programme is when the flag leaf is fully emerged on the main stem; note this will mean that flag leaves will be partially emerged on the side tillers. With large acreages it is better to start at GS37 when the flag leaf is starting to emerge on the main stem and finish at GS39, than it is to start GS39 and finish at GS45 (boots swollen on main stem). This is important with a susceptible variety portfolio and no seed treatment coverage against foliar diseases.

Rate – With a single spray approach the rate should be tailored to the length of the grain fill and the resistance rating of the variety/seed treatment

Risk – the risk with this strategy is if disease comes into the crop at GS31-32, wet weather diseases such as Yellow spot, *Septoria tritici* or early stripe rust on very susceptible varieties. In this scenario leaf 3, but more importantly leaf 2, are left unprotected while waiting for the flag leaf to emerge.

Priority - With the 1 spray approach it is important to target the susceptible /moderately susceptible varieties in the acreage first or those crops which had no foliar disease control element in the seed treatment.

Optimum 1 spray approach GS37-39

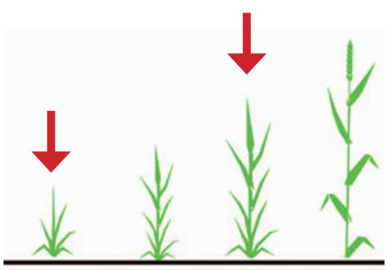


Two spray approaches in wheat– prompted by disease development before flag leaf emergence

In 2004 the WA strain of stripe rust developed in many wheat crops prior to flag leaf emergence. In this situation growers are faced with having to resort to 2 fungicides (assuming upfront products with longer persistence e.g. Jockey seed treatment or Impact in furrow have not been employed). As a consequence there are a number of different strategies that can be applied which have similar outcomes.

Timing – In the **traditional 2 spray approach** the first spray protects leaf 3 the second the flag leaf when fully emerged (GS39). The overlap between the 2 sprays protects leaf 2. Most appropriate for wet weather/early disease pressure scenarios e.g Yellow spot, *Septoria tritici* or early stripe rust. Consider propiconazole (Tilt/Bumper) for Yellow spot situations.

Traditional 2-spray programme



In the **straddle 2 spray approach** (so called because timings straddle flag leaf emergence) the first spray protects leaf 2, the second protects the ear and flag leaf. Note the second spray should be targeted at ear emergence GS55-59 (50%-100% of the ear emerged) and no later. This approach gives more time (i.e. GS30 –33) to see if disease development is progressing up the canopy before the first application is made.

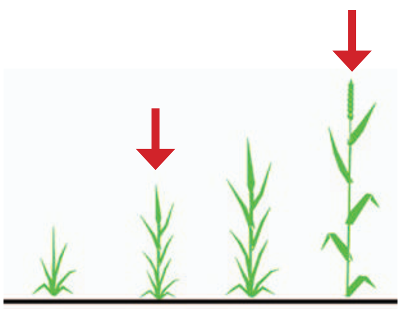
Rate – With the traditional approach the first spray protects the less important leaves i.e. leaf 3 and 4. Thus expenditure can be reduced by selecting a cheaper product or using a lower rate (e.g. triadimefon for stripe rust), saving main expenditure for the flag leaf timing.

In the case of the straddle it is more difficult to make a case for different levels of expenditure since both sprays are of equal importance.

Risk – the risk of the traditional approach is if disease pressure is high and the flag leaf spray is delayed, leaf 2 is unprotected. Some growers prefer to wait for the ear to emerge, which then puts the 2 most important leaves at risk (flag and leaf 2).

When a straddle approach is adopted the flag leaf is at risk if the ear emergence spray is delayed, as are leaves 3 and 4 under high early disease pressure.

Straddle 2-spray programme



Priority – Starting with an initial fungicide at GS32 the traditional 2 spray is more suited where high spring rainfall is linked with varieties susceptible to Yellow spot (wheat on wheat situations), *Septoria tritici* and stripe rust. However the flag leaf spray cannot be delayed past GS39.

With the straddle approach there is timing flexibility at flag leaf allowing for a later second spray. This may give a better ability to reassess the need for a second spray in light of seasonal moisture availability, disease pressure and weather. It would also give a better ability to protect late disease issues such as stem rust or head diseases.

Wheat canopy cv Mackellar with and without fungicide

Management Strategies for Barley

Management strategies for barley are more complicated than wheat as:

- Lower leaves which emerge earlier are relatively more important.
- The flag leaf is relatively small and unimportant in barley, compared to wheat and is therefore not the convenient mid season focal point for strategies.
- Earlier more important leaves that require fungicide application create a later season gap in protection therefore making two sprays more effective in this crop.
- Two spray programmes increase the likelihood of fungicide rate reduction with each spray. In wheat fungicide activity against rusts is very effective at low rates, however, our existing range of fungicides do not control barley diseases as effectively at equally low rates.
- Barley often suffers from wet weather diseases, such as Scald, early in the season, but then is subject to drier/warmer weather diseases later in the season, again making it more difficult to target a single spray programme under diverse disease pressure.

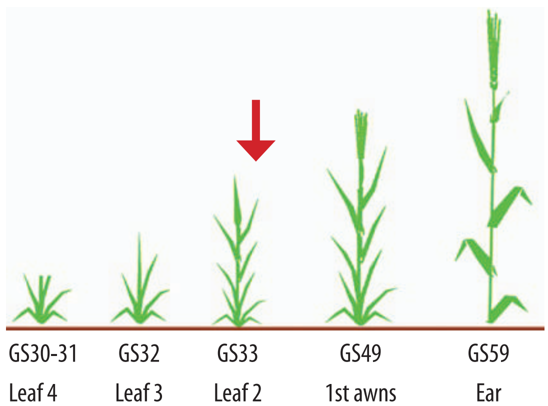
Effect of resistant cultivars and seed treatments

Again, as with wheat, consider the influence of seed treatments and cultivar resistance to the main diseases expected, since it is likely that both will delay the disease epidemic. Monitoring should begin earlier in barley than in wheat since leaf 4 (F-3) is more important in this crop than in wheat.

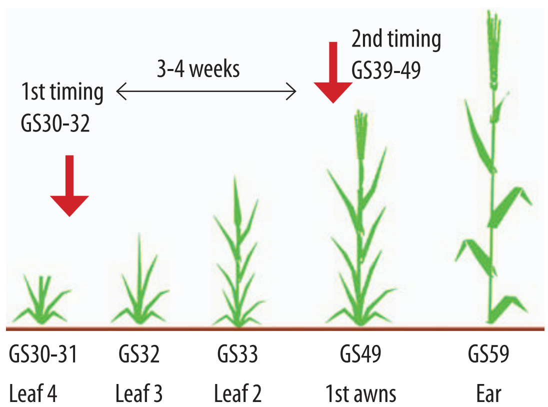
Barley has a greater range of weaknesses

Unlike wheat it is far more difficult to pinpoint single fungicide timing, since the flag leaf is less important. In addition most of the popular varieties have some disease weaknesses e.g. Gairdner. Therefore monitor from late tillering GS25 for the presence of disease on the older leaves. Consider application based on propiconazole (Tilt, Bumper) where net blotch and or Scald are in evidence on newer leaves at GS30 or triadimefon (Triad/Bayleton) for mildew.

Less easy to adopt single spray in Barley - however 1 spray best targeted at leaf 2 emergence (F-1) GS 33-37



When disease pressure is high from GS30 there are 2 focal points for Barley



Rotation position

Rotation position will play a bigger role in barley strategies since barley after barley is high risk. If no disease develops at GS30-31 continue to monitor through until GS49 (1st awns emerging). A critical midpoint is GS33 (3rd node) which marks the emergence of the most important leaf in barley (leaf 2 or F-1). If a single spray were deemed to be the best option then this would be the optimum timing.

2nd Spray timing

At GS49 (1st awns emerging) consider a second spray if the first was applied at GS30-31. Leaf rust tends to build up later in the season compared to net blotch or Scald - consider either propiconazole (Tilt/Bumper) or tebuconazole (Folicur), the latter being reserved for situations where leaf rust is dominant at this second timing.

5. Strobilurin fungicide response

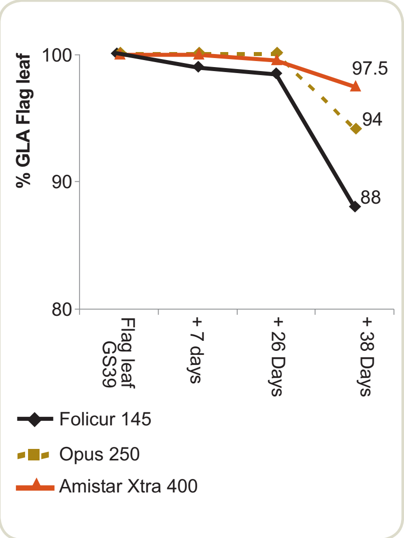
Project results showed that strobilurin fungicides offer a greater degree of disease protection than other available fungicides. However this did not translate into sufficient yield increases over and above triazole fungicide programmes to make it economic. Wheat diseases such as the stripe rust can be controlled very effectively by triazole fungicide spray programmes costing little more than $10/ha (not including cost of application). For the vast majority of situations, based on current costs and grain prices, it is difficult to justify the use of the new strobilurin fungicides, unless faced with severe disease pressure and growing with very high yield expectation.

The project produced some trial evidence to suggest that Strobilurins (azoxystrobin in wheat & barley and trifloxystrobin in barley) offer:

- Superior disease protection particularly against leaf rust in barley and wheat (azoxystrobin).
- As a result of superior disease control in some trials, crops were observed to stay greener for longer, particularly in the high rainfall zone though even barley grown in the mallee showed small effects.
- Typically strobilurin benefits over triazole (e.g. Folicur and Tilt) did not express themselves until approximately 4 weeks after application.
- Unfortunately in all but 2 of the 13 trials strobilurin benefits have not translated into sufficient yield to make it cost effective.
- There is no doubt that strobilurins have created yield increases over the last 2 years of Australian trials, however with a mean response of between 0 – 3%, depending on rate, the effect has typically been uneconomic based on current product costs and grain prices.

The protectant activity offered by strobilurins is more persistent than the existing triazole products. It is this protection which potentially leads to enhanced green leaf retention at grain fill and higher yields.

Strobilurin benefit over triazole (such as Folicur), tended to show up approximately 4 weeks after product application, as the example (below) from Lake Bolac, in Victoria's high rainfall zone, illustrates.

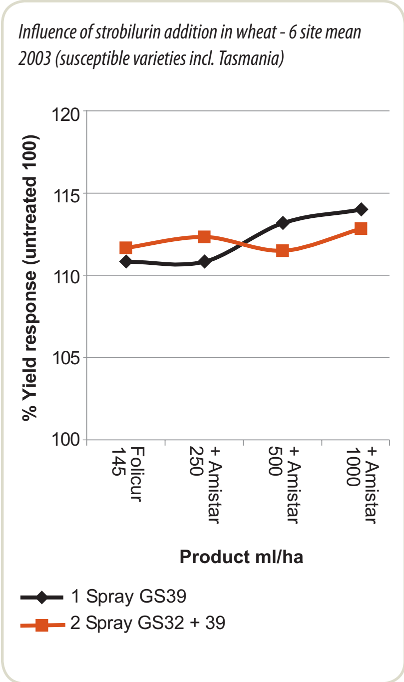


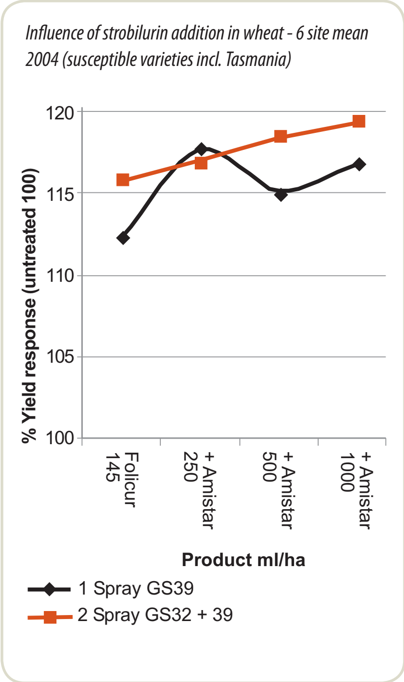
Disease Management

Soil water constraint

Even in the high rainfall zone low soil moisture status and higher temperatures frequently curtailed strobilurin green leaf retention during grain fill, thus reducing the yield impact of these products as the following 2003 and 2004 project results illustrate.

Strobilurin response in susceptible wheat cultivars – 2003 & 2004 Influence of fungicide application on wheat with and without strobilurin (% yield relative to the untreated =100)





Az = Amistar 250SC is a Group K strobilurin which is not approved for use in cereals but gave the project team the ability to assess increasing rates of strobilurin fungicide independently of the group C triazole fungicide. At 500ml/ha Amistar 250 SC contains the same amount of the strobilurin (azoxystrobin) as 625 ml/ha Amistar Xtra.

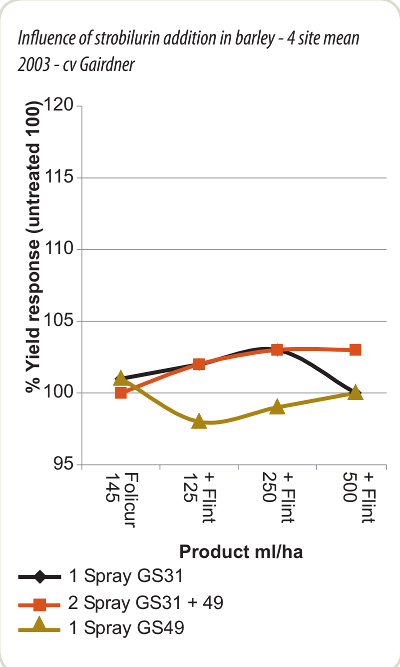
N.B. Amistar Xtra at 625ml/ha applied the same amount of strobilurin (azoxystrobin) as the Folicur + Amistar 500ml/ha. The yield of 1 spray Amistar Xtra = 118.8% and 2 spray = 117.6% in the same 6 site mean

Untreated

Triazole treated (Tilt)

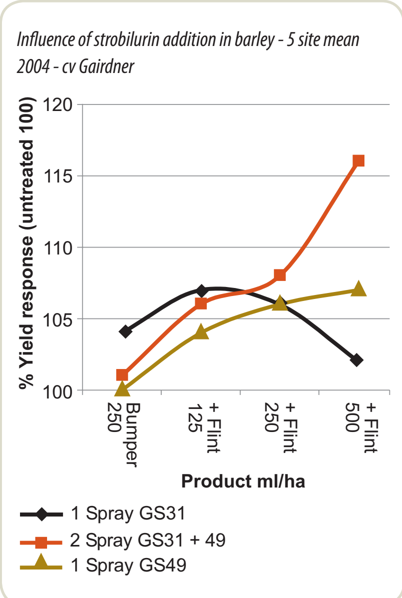
Strobilurin treated (Tilt + Amistar)

Strobilurin response in Gairdner barley – 2003 & 2004. Influence of fungicide application on barley with and without strobilurin (% yield relative to the untreated =100)



Notes: 1 and 2 spray programmes applied the same amount of active ingredient.

Flint 500WG is a Group K strobilurin which is not approved for use in cereals but gave the project team the ability to assess increasing rates of strobilurin fungicide independently of the group C triazole fungicide (Folicur in 2003 & Bumper in 2004) .



N.B. Amistar Xtra at 400ml/ha in the 1 spray programmes yielded 100 at GS31, 103 at GS49 and when applied twice 108 in the same 5 site mean.

Key Points in wheat

- Strobilurins created yield benefits of between 0-3% (depending on rate) over the triazole fungicide Folicur when applied in wheat (6 site mean).
- Responses were generally rate dependent and typically in the 0.1 – 0.3 t/ha range.
- The advantage of strobilurin was slightly greater if fungicide active was applied in single sprays as opposed to split application.
- Overall these small benefits were independent of the overall response to fungicide but would not have been economic based on 2004 strobilurin costs.
- Note that in 2004 the new triazole Opus (epoxiconazole) achieved similar yield levels to the strobilurin treatments.
- The only sites to offer cost effective returns over and above a 2 spray triazole regime were where there were very high disease pressure situations combined with high yield potential (in the project these being HRZ in south east South Australia cv H45 and Tasmania cv Mackellar).

Key Points in barley

- Under high disease pressure barley diseases, such as net blotch and scald are more difficult to control with group C triazoles than rusts in wheat.
- In these situations Strobilurins offer yield benefits but in project results only at the highest rates, which would be uneconomic.
- The key strength of the current strobilurin available (Amistar Xtra) is leaf rust where benefits could be secured from lower rates under high disease pressure.

References (for further reading)

Trial Results Manual – Southern Farming Systems 2002, 2003 & 2004 – available from Southern Farming Systems – email: office@sfs.org.au

BCG WFS 2003/04 Wimmera & Mallee Crop and Pasture Production Manual – email: admin@bcg.org.au

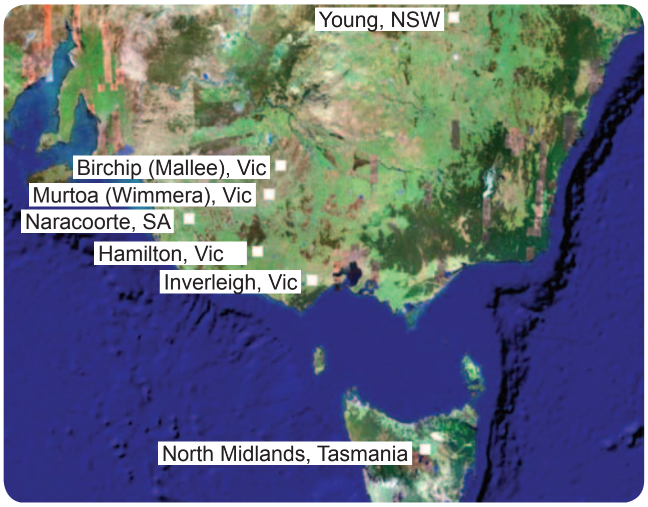
BCG WFS 2004/05 Wimmera & Mallee Crop and Pasture Production Manual

Mackillop Farm Management Group – Trial Results for 2004 – email: office@sfs.org.au

Grains Research Adviser Update (Southern region) – Feb 2004 – available on GRDC website: www.grdc.com.au

GRDC – Cereal Foliar Disease Workshops for Advisers (ICAN) – July 2004 – available on GRDC website: www.grdc.com.au

Trial Site Locations for GRDC project SFS 00006



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Author: Nick Poole, FAR

Graphic design: Simon Hayes, Crop & Food Research, Lincoln, New Zealand.

Photos: Robert Lamberts, Crop & Food Research, Lincoln, New Zealand.